STANFORD LINEAR ELECTRON ACCELERATOR

HEARINGS

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT

AND THE

SUBCOMMITTEE ON LEGISLATION

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY

CONGRESS OF THE UNITED STATES

EIGHTY-SIXTH CONGRESS

FIRST SESSION

ON

STANFORD LINEAR ELECTRON ACCELERATOR

JULY 14 AND 15, 1959

Printed for the use of the Joint Committee on Atomic Energy

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STANFORD LINEAR ELECTRON ACCELERATOR

TUESDAY, JULY 14, 1959

CONGRESS OF THE UNITED STATES,
SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT,
AND THE SUBCOMMITTEE ON LEGISLATION,
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D.C.

The subcommittees met at 10 a.m., pursuant to notice, in room P–63, the Capitol, Hon. Melvin Price presiding.

Present: Representatives Price, Aspinall, Van Zandt, Bates, and Westland; Senators Anderson, Jackson, Dworshak, and Bennett.

Also present: James T. Ramey, executive director; David R. Toll, staff counsel; George E. Brown, Jr., professional staff member; and Edward J. Bauser, technical adviser, Joint Committee on Atomic Energy.

Representative PRICE. The committee will be in order.

This is the first of 2 days of public hearings by the Joint Committee on Atomic Energy on the proposed 2-mile Stanford linear accelerator. The hearings are being scheduled jointly by the Research and Development Subcommittee, and the Subcommittee on Legislation.

On May 27 of this year, the AEC requested an authorization of $105 million for the proposed Stanford accelerator, which is to be 10,000 feet long, and have an initial energy of 10 to 15 billion electron volts.

The accelerator would be constructed on the grounds of the Stanford University at Palo Alto, Calif.

Bills have been introduced in the House and Senate to provide authorization for this project. During the morning session today we will have testimony from Chairman McCone, Commissioner Floberg, Dr. John Williams of the AEC Research Division, and Dr. Leland Haworth, Director of Brookhaven National Laboratory. The testimony will cover the technical background and financial aspects of the proposed accelerator.

This afternoon the committee will receive presentations from representatives of Stanford University, including Dr. Ginzton, Director of the project, and Dr. Brobeck, of Brobeck Associates, who were commissioned by the AEC to make a cost review of the Stanford proposal in 1958.

We will also have two brief statements during the course of the day from Congressman Younger and Congressman Gubser, of California, regarding the project.

Congressman Younger is present now; we will permit him to make his statement at the start of the hearing. If he is not here, well take him whenever he appears.

Tomorrow morning the committee will receive the views from experts not directly connected with the Stanford project, including Dr.

Smyth of Princeton, Dr. Rollefson of the Midwestern Universities Research Association, and Dr. Ramsey, or Harvard-MIT electron accelerator project.

Before we proceed with our first witness, I would like to place in the record at this point, the press release announcing these hearings, the bill S. 2073, a letter from AEC Chairman McCone, dated May 13, 1959, announcing the President's decision, a letter from Chairman McCone, transmitting the proposed bill, analysis of the bill and the construction project data sheet. Also following is a letter dated July 8, 1959, to the AEC, requesting the presentation of certain information at this hearing.

PRESS RELEASE NO. 233, JULY 9, 1959

From the Office of the Joint Committee on Atomic Energy

Public hearings on the proposed $105 million Stanford linear electron accelerator are scheduled to be held by the Joint Committee on Atomic Energy, July 14 and 15, it was announced today by Senator Clinton P. Anderson, committee chairman. The hearings will be conducted jointly by the Research and Development Subcommittee and Subcommittee on Legislation.

The proposed accelerator, which is to be 10,000 feet long and have an initial energy of 10–15 billion electron volts, would be constructed in a tunnel on the grounds of Stanford University in Palo Alto, Calif., and would take about 6 years to construct. A request for authorization of the project was submitted to the Joint Committee by the Atomic Energy Commission on May 27, following a review by a special Presidential advisory panel.

Chairman McCone, of the AEC, is scheduled to make the initial presentation on July 14, starting at 10 a.m. He will be followed by Dr. John Williams, director of the AEC Research Division, and Dr. Lee Haworth, director of Brookhaven National Laboratory and member of the President's advisory panel.

In the afternoon session, beginning at 2 p.m., representatives of Stanford University will testify, including Dr. Edward Ginzton, director of the Stanford Microwave Laboratory. They will be followed by William M. Brobeck, whose firm, Brobeck Associates, was commissioned by the AEC to make a cost review of the Stanford proposal in 1958.

The hearing will continue the morning of July 15, beginning at 10 a.m., at which time experts not directly connected with the Stanford project will present their views. Witnesses will include Dr. Henry DeWolf Smyth, chairman of board of scientific and engineering research, Princeton University; Dr. R. Rollefson, president of the Midwestern Universities Research Association (MURA); and Dr. N. F. Ramsey of the Harvard-MIT electron accelerator project.

[S. 2073, 86th Cong., 1st sess.]

A BILL To authorize appropriations for the Atomic Energy Commission in accordance with section 261 of the Atomic Energy Act of 1954, as amended, and for other purposes

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That there is hereby authorized to be appropriated to the Atomic Energy Commission the sum of $105,000,000 for the construction of a linear electron accelerator, together with necessary buildings and appurtenances thereto.

SEC. 2. The Atomic Energy Commission is authorized to start the project provided for in section 1 hereof only if the currently estimated cost of that project does not exceed by more than 25 per centum the estimated cost set forth for that project.

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., May 13, 1959.

DEAR SENATOR ANDERSON: As you know, the executive branch has undertaken a review of the Federal support of high energy accelerator physics. This study has been carried out by the President's Science Advisory Committee, the Com-

mission's General Advisory Committee, the Atomic Energy Commission, the National Science Foundation, and the Department of Defense. It has been coordinated by the President's Science Adviser, Dr. Killian. Matters of management and the question of the distribution of Federal Government responsibilities in this field have been considered by the Bureau of the Budget.

The need to review the high energy accelerator program at the national level stems from the high cost of construction of high energy accelerators, necessitating Federal support. The problem has been studied periodically by a special NSF panel. Their most recent report is enclosed (attachment 1).

Following the latest report of the NSF panel, Dr. Killian convened a special panel of the President's Science Advisory Committee and the Commission's General Advisory Committee. The report of this panel, which is to be issued by the White House as a public document, was sent to you on May 11 and is attached herewith (attachment 2).

Following the report of the panel, there has been recommended to the President, and he has now concurred in moving forward with the construction of a high energy electron accelerator to be constructed at Stanford University. It is our understanding that the President will make a public announcement of this fact in an address he will give on Thursday, May 14. The Commission in the meantime is moving forward to prepare the necessary request for authorization for the construction of this machine which would be initiated in fiscal year 1960.

Sincerely yours,

JOHN A. MCCONE, *Chairman.*

Enclosures:

1. NSF report, August 7–8, 1958 (see app. 1, p. 251).
2. NSF report, October 25, 1956 (see app. 1, p. 235).
3. Report by special panel dated November 25, 1958 (see app. 2, p. 527).

U.S. ATOMIC ENERGY COMMISSION,
Washington D.C., May 27, 1959.

Hon. CLINTON P. ANDERSON,
Chairman, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR SENATOR ANDERSON: I have submitted today to the Speaker of the House of Representatives and to the President of the Senate proposed legislation which would authorize appropriations to the Atomic Energy Commission in the amount of $105 million for the construction of a linear electron accelerator, together with the necessary buildings and appurtenances.

On May 14, 1959, the President announced in an address in New York City that this project had been approved by him and that legislation would be submitted promptly to secure the necessary authorization. This legislation is in implementation of that announcement.

The proposed 10–15 billion electron volt accelerator will be a major advance in the machines available to science for investigating the nature of matter and energy. Because of its high energy, it will increase the ability of scientists to probe into the structure of the atomic nucleus. Each previous advance in the energy of particle accelerators has led to important discoveries. The proposed machine will make major contributions to our understanding of nuclear phenomena.

We plan on constructing the accelerator at Stanford University as a national facility for research, to be used by scientists from other institutions as well as those at Stanford University. It will be approximately 2 miles long and will take about 6 years to construct.

The Bureau of the Budget advises that this proposal is in accord with the program of the President.

Copies of the proposed legislation, the analysis of the project and the project data sheets are enclosed.

Sincerely yours,

JOHN A. MCCONE, *Chairman.*

A BILL To authorize appropriations for the Atomic Energy Commission in accordance with section 261 of the Atomic Energy Act of 1954, as amended, and for other purposes

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That there is hereby authorized to be appropriated to the Atomic Energy Commission the sum of $105,000,000 for the construction of a linear electron accelerator, together with necessary buildings and appurtenances thereto.

SEC. 2. The Atomic Energy Commission is authorized to start the project provided for in section 1 hereof only if the currently estimated cost of that project does not exceed by more than 25 per centum the estimated cost set forth for that project.

BILL ANALYSIS

Linear electron accelerator, $105 million

This project provides for the design and construction of a high energy electron accelerator at Stanford University. The description set forth below represents present planning for this machine and associated support facilities. Definitive design of the machine and technological development during the design and construction period may necessitate some changes in the project.

The machine will be of linear design approximately 2 miles in length, and in the initial stages will achieve an energy range of 10–15 billion electron volts. Design and construction of the machine and associated facilities will require approximately 6 years beginning in fiscal year 1960.

The accelerating tube is to be housed in a horizontal tunnel approximately 10 feet wide and deep enough in the ground to provide the necessary shielding. A parallel tunnel approximately 24 feet wide will contain the radio frequency equipment and wiring. The two tunnels are to be separated by approximately 35 feet of earth so that personnel can service the equipment during accelerator operation.

The accelerator will be powered by 240 klystron amplifiers. Initial operation of each klystron is planned at 6 megawatts, giving a beam of 10 billion electron volts electrons. With present-day techniques the klystron power may be increased to give a beam of 15 billion electron volts.

The tunnel, wave guides, accelerator tube, and power facilities are planned so that the beam energy may be further increased to 45 billion electron volts by adding additional klystron amplifiers as necessary.

The proposed electron linear accelerator will provide at 10 billion electron volts the highest energy electron beam in the world. Its average current of 30 microamperes is at least 50 times greater than can be attained with a circular machine.

The beam is easily extracted and its small angular divergence makes possible great precision in experiments. An accelerator with these characteristics has been strongly recommended by a special panel of the President's Science Advisory Committee and the General Advisory Committee to the Atomic Energy Commission, and approved by the President.

It is presently planned that the accelerator will be built on land owned by Stanford University. Appropriate arrangements, including a long-term lease of the land, will be negotiated between the Atomic Energy Commission and Stanford University.

CONSTRUCTION PROJECT DATA SHEET

SAN FRANCISCO OPERATIONS OFFICE; PHYSICAL RESEARCH SUBPROGRAM

1. Title and location of project: Linear electron accelerator.
2. Project No.——.
3. Date physical construction begins: Second quarter fiscal year 1960.
4. Date physical construction ends: Fiscal year 1965.
5. Previous cost estimate: $0.
6. Current cost estimate: May 15, 1959, $105 million.

7. Obligations and cost schedules: This detail represents present planning for this machine and associated support facilities. Definitive design and technological development may necessitate changes at a later date.

Fiscal year	Obligations	Cost	Activity
1960	$3,700,000	$2,000,000	Architect-engineer studies on buildings, site development and grading, initiation of construction on administration buildings, klystron laboratory and electric feeder line.
1961	12,000,000	7,000,000	Design of tunnel, target facilities, electrical distribution systems, roads, and utility areas. Construction of engineering and service building, general services building, warehousing facilities, accelerator fabrication facility, and shops. Design and construction of standard accelerator section.
1962	50,000,000	30,000,000	Systems and component design. Construction of target facility. Installation of electrical facilities. Construction of tunnel and the initiation of construction of the accelerator proper.
1963	22,000,000	36,000,000	Continuation of design of the accelerator and component testing. Continuation of construction of tunnel accelerator components. Initiation of construction of instrumentation for the accelerator.
1964	15,000,000	18,000,000	Component testing and assembly of machine. Completion of tunnel, accelerator, and instrumentation.
1965	2,300,000	12,000,000	Component and system testing and startup of accelerator.
Total	105,000,000	105,000,000	

8. Brief physical description of project: This project provides for the design and construction of a high energy electron accelerator at Stanford University. The description set forth below represents present planning for this machine and associated support facilities. Definitive design of the machine and technological development during the design and construction period may necessitate some changes in the project. It is planned that the accelerator will be built on land owned by Stanford University. Appropriate arrangements, including long-term lease of the land, will be negotiated between the AEC and Stanford University.

The machine will be of linear design approximately 2 miles in length and in the initial stages will achieve an energy of 10 to 15 Bev. The average current delivered to the target will be approximately 30 microamperes. Two hundred forty klystrons operating at a frequency of 2,856 megacycles per second will power the accelerator. The accelerating tube is to be housed in a horizontal tunnel approximately 10 feet wide which will be deep enough in the ground to provide the necessary shielding. A parallel tunnel approximately 24 feet in width will contain the radiofrequency equipment and wiring. The two tunnels are to be separated by approximately 35 feet of earth so that personnel can service the equipment even though the accelerator is in operation.

One advantage of a linear machine over a circular machine such as a synchrotron is that there is no problem in extracting the electron beam from the accelerator. It is planned to provide a beam switchyard after the beam emerges from the tunnel where the beam can be directed into three different experimental areas. In these areas it will be necessary to provide movable shielding blocks so that a variety of experimental arrangements are possible. It is planned to have two of the beams brought into a test house which will be approximately 400 feet long to provide adequate space for experiments. This building will have four large cranes (approximately 100 tons each) with approximately 75 feet overhead clearance.

Another advantage of the linear accelerator is that the energy can be increased by increasing the power of the klystron amplifiers. Initial operation of each klystron is planned at 6 megawatts which will give a beam of 10 Bev. electrons. With present day techniques, the klystron power may be increased to give a beam of 15 Bev. The tunnel, waveguides, accelerator tube, and power facilities are being planned so that at a later date the beam energy may be further increased to 45 Bev., if the situation in physics at that time is such as to make a higher energy electron beam desirable.

The proposed accelerator will utilize basic components which have previously been developed by the Stanford University research staff. The present mark III linear machine at Stanford has operated successfully for several years at energies as high as 730 Mev. To build a higher energy accelerator requires a longer machine of the type already in operation. Previous performance

indicates that 24-hour operation will be possible. It is planned to divide the 2-mile accelerator into approximately 40 250-foot sections, which can be alined and tuned individually during start-up operations. Several of these sections can be inoperative (by klystron failure, for example) without affecting the operations of the accelerator as a whole.

Although further theoretical, experimental, and engineering studies may cause some changes, the principal features of the machine and associated facilities are planned as follows:

Initial energy	10 Bev.
Length	10,000 feet.
Pulse length	2.5 microseconds.
Repetition rate	360 pulses per second.
Operating time	24 hours per day.
Number of klystrons	240.
Initial power output per klystron	6 megawatts.
Expected average klystron life	2,000 hours.
Number of klystrons to be repaired per month.	90.
Installed electrical capacity	60 megawatts.
Frequency	2,856 megacycles per second.
Gun pulse length	0.02–1.7 microseconds.
Gun injection voltage	80 kilovolts.
Peak beam current	50 milliamperes.
Average beam current	30 microamperes.
Average beam power	0.3 megawatts.
Maximum beam duty cycle	1/2,000.
Initial energy gradient	1.0 Mev/feet.
Minimum shielding requirements:	
(*a*) Transverse	29 feet of earth.
(*b*) In-line	45 feet of earth.
Accelerator tunnel cross section	10 by 10 feet with a 3-foot-high dome.
Klystron tunnel cross section	24 by 10 feet with a 10-foot-high dome.
Tunnel separation	35 feet.

Building and structures

Structure	Size	Special requirements
a. End station main building	200,000 square feet, 98 feet high.	4–100/15-ton cranes; floor load, 2.5 kips/square feet.
b. End station auxiliary buildings	41,000 square feet	Research laboratory radio frequency room, air conditioned.
c. General services	14,000 square feet	
d. Klystron laboratory	36,500 square feet	Clean room, air conditioned.
e. Accelerator storage and shops	46,000 square feet	Electroforming shop; air conditioned.
f. Administration and engineering building	42,000 square feet	
g. Accelerator control room	5,000 square feet	Pressurized.
h. Auditorium	3,000 square feet	
i. Cafeteria	4,500 square feet	
j. Fire station	1,000 square feet	
k. Guard houses	1,000 square feet	
l. D.c. generator building	21,000 square feet	

9. Justification of need: The proposed electron linear accelerator will provide at 10 Bev., the highest energy electron beam in the world. Its average current of 30 microamperes is at least 50 times greater than can be attained with a circular type machine. The beam is easily extracted and its small angular divergence of 10^{-5} radian makes possible great precision in experiments. An accelerator with these characteristics has been strongly recommended by a special panel of the President's Science Advisory Committee and the General Assembly Committee to the Atomic Energy Commission, and approved by the President.

At the present time there are four categories of problems which could very fruitfully be explored with a high intensity 10 Bev. electron beam: (*a*) nucleon structure; (*b*) studies of production cross section via photoproduction, direct electron production, and by the study of the spectra of inelastically scattered electrons; (*c*) the production of beams of unstable particles and the study of

their interactions; (*d*) investigation of the question of the limits of quantum electrodynamics.

(*a*) Some of the most interesting work done on the 730 Mev., Stanford linear accelerator has been the study of nucleon structure by electron scattering. Although the interpretation of these experiments is expected to become more difficult above 1 Bev., this type of work will continue to be more and more informative as the energy is increased.

(*b*) The study of the photoproduction and direct electron production of the various particles will contribute greatly to our physical understanding, since these processes are less complex than direct nucleon-nucleon production. High current is necessary because the cross sections are small. The machine energy of 10 Bev. is large enough so that all the known particles and antiparticles can be produced. A further possibility is that presently unknown weakly interacting particles may be produced by electromagnetic pair production.

(*c*) Since all the known particles are produced with high intensity, the accelerator can be used as a source of these particles for a great variety of experiments.

(*d*) All the experiments considered above interact strongly with the basic question of the validity of quantum electrodynamics at high momentum transfers. Electron-electron scattering, large angle pair production, and bremsstrahlung will be investigated at these energies.

In addition to the total estimated cost of $105 million for the construction project, there will be other associated costs. During the construction period of about 6 years, the research and development costs directly related to the construction of the accelerator are estimated at approximately $18 million.

Once the accelerator is placed in operation, the annual recurring cost for operating the machine and for the conduct of the research program on the accelerator is estimated to be approximately $15 million. Because of the long lead time required for the development of research apparatus and the need to build up the research program in advance of initial operation of the accelerator, it is anticipated that the research—oriented operating program will be initiated about 3 years prior to machine startup. Thus a smooth transition to the research-operating phase will require substantial operating expenditures during the later part of construction. These costs would be in addition to the $18 million research and development costs referred to above.

Subsequent to completion of the project, minor capital improvements and machine modifications may also be required that could range from $1 to $2 million annually. Other capital additions in later years may also be required.

Depending on the success in the development of components and the existence of a valid scientific need, it may become desirable to increase the beam energy above 10–15 Bev. Such upgrading of the technical specifications would involve expenditures in addition to those described above.

10. Details of cost estimates (these estimates represent present planning for this machine and associated support facilities. Definitive design, engineering, and technological developments may necessitate changes at a later date):

	Estimated cost
A. Engineering, design, and inspection at 10 percent of construction costs	$7, 600, 000
B. Land and land rights	0
C. Construction costs	74, 651, 000
1. Improvements to land	1, 956, 000
2. Buildings	10, 500, 000
3. Utilities	12, 042, 000
4. Tunnels	16, 764, 000
5. Accelerator	23, 789, 000
6. Equipment	9, 600, 000
D. Escalation	9, 349, 000
E. Contingency at 15 percent of all other costs	13, 400, 000
Total project cost	105, 000, 000

10a. Details of fiscal year 1960 obligations (present planning indicates obligations for the following construction activities will be required in fiscal year 1960. Based on A–E work, construction scheduling and technological developments, this breakdown is subject to change):

	Estimated cost
A. Engineering, design, and inspection	$175,000
C. Construction	3,147,000
1. Improvements to land	435,000
2. Buildings	1,112,000
3. Utilities	540,000
4. Accelerator	500,000
5. Equipment	560,000
D. Contingency	378,000
Total fiscal year obligations	3,700,000

11. Major contractor and intended type of contract: Competitive lump-sum contracts will be used wherever practicable. However, it is recognized that for certain phases of the project, cost-type contracts may be desirable.

A BILL To authorize appropriations for the Atomic Energy Commission in accordance with section 261 of the Atomic Energy Act of 1954, as amended, and for other purposes

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That there is hereby authorized to be appropriated to the Atomic Energy Commission the sum of $105,000,000 for the construction of a Linear Electron Accelerator, together with necessary buildings and appurtenances thereto.

SEC. 2. The Atomic Energy Commission is authorized to start the project provided for in Section 1 hereof only if the currently estimated cost of that project does not exceed by more than 25 per centum the estimated cost set forth for that project.

CONGRESS OF THE UNITED STATES,
JOINT COMMITTEE ON ATOMIC ENERGY,
July 8, 1959.

Gen. A. R. LUEDECKE,
General Manager,
U.S. Atomic Energy Commission,
Washington, D.C.

DEAR GENERAL LUEDECKE: This is to confirm arrangements for Commission participation in public hearings before the Joint Committee, July 14 and 15, on requested authorization of $105 million for the Standard linear accelerator.

It is understood that the Commission will lead off the morning session starting at 10 a.m., July 14, with a presentation on the technical and financial justification for the project. In the afternoon session, starting at 2 p.m. representatives of Stanford University and Brobeck Associates are scheduled to appear.

The second day of the hearings, scheduled for the morning of July 15, starting at 10 a.m. is being reserved for expert witnesses not directly connected with the project whose comments are being solicited.

It is requested that in its presentation the Commission be prepared to cover in detail the following points:

(1) What portion of the Nation's planned future accelerator construction and operating cost does the proposed Stanford accelerator represent?

(2) In view of the fact that the President's Advisory Panel recommended that highest priority be given to improving existing accelerators, what is the need at this time for constructing a new accelerator of this magnitude and cost?

(3) Why was the submission of the Stanford proposal deferred to this late date (May 27, 1959) considering the fact that Stanford developed the basic proposal in 1956 and the President's Advisory Panel completed its report recommending the project in November 1958?

(4) What plans have been developed to implement the construction of other accelerators recommended by the President's Special Advisory Panel?

(5) The original Stanford cost estimate for the proposed project was $78 million. The Brobeck Associates estimate was $115 million. The cost estimate contained in the current proposal is $105 million, exclusive of the $18

million for research and development. What are the reasons for these differences in cost estimates?

(6) Why should the full $105 million be authorized at this time? Why shouldn't the initial authorization be limited to design and engineering studies and associated research and development?

(7) Why is construction of the Stanford accelerator proposed at this time since the 6 Bev. Cambridge electron accelerator is scheduled to be completed next year? Should the construction of the Stanford accelerator be deferred until data is obtained from the Cambridge accelerator concerning the fruitfulness of experimental work with high-energy electrons?

(8) Were comments obtained from outside experts on the proposed Stanford accelerator as was done on the MURA proposal in 1957? Are these comments available or documents available summarizing these comments?

(9) Why is construction of the accelerator being proposed at the Stanford site? Were other sites considered? What about Livermore?

(10) Has a survey been made of experts regarding the scientific need of such an accelerator, and, if so, are documents available indicating the results of the survey?

(11) What plans have been developed for use of the accelerator on a national basis with participation by scientists from other universities and laboratories?

(12) In testimony before the Joint Committee on the fiscal year 1960 authorization bill, the Commission stated that a policy should be established prior to the authorization of facility construction at the campuses of private universities. Has a policy been established on this matter? If so, what is it and how is it being applied to the Stanford project?

(13) Will the technology developed in the design, construction, and operation of the proposed accelerator be of any value to military programs? If so, in what way and for what specific application?

(14) What considerations were given to geological conditions in the vicinity of the proposed site, particularly with regard to stabilities of the underlying ground and the possibility of earthquakes?

(15) Since the energy to be developed in the presently proposed accelerator is 10 to 15 Bev., why is it necessary to build a 2-mile linear accelerator?

(16) The proposal originally submitted by Stanford covered a 15- to 25-Bev. accelerator while the present proposal refers to an energy range from 10 to 15 Bev. Why was the energy decreased?

(17) The proposal refers to the possibility of a future modification of the accelerator to increase the energy to 45 Bev. What is the probability of such a modification being made? What is the estimated cost of such a modification?

(18) What specific research and development work is to be done with the $18 million referred to in the proposal since the accelerator is understood to be based on proven concepts?

(19) What arrangements are planned for the assignment of responsibilities for the various phases of the architect-engineering and construction work for the proposed project? For example, is it planned that the Commission will assume responsibility for contracting directly for certain phases of the work and Stanford will assume responsibility for contracting for other items? How does the planned arrangement for this project compare with the Commission's experience on other large construction projects?

(20) How does the U.S. high-energy accelerator program compare with other nations, particularly Soviet Russia? Does the U.S.S.R. now have or is it planning construction of a high-energy electron accelerator comparable to the proposed Stanford project?

The Commission's cooperation in this matter is appreciated.

Sincerely yours,

JAMES T. RAMEY, *Executive Director.*

(Also included as app. 1 (p. 233), is a letter dated July 2, 1959, from the AEC, supplying background material on the proposed accelerator project.)

Representative PRICE. Chairman McCone will lead off for the Commission, followed by Commissioner Floberg. Would you proceed?

STATEMENT OF JOHN A. McCONE, CHAIRMAN, ATOMIC ENERGY COMMISSION

Mr. McCone. Thank you very much, Mr. Chairman. The Commission is pleased with this opportunity to discuss the Stanford accelerator project with the Joint Committee. I do not have a prepared statement of my own. The Commission has a prepared statement which will be given by Commissioner Floberg. It will be followed by a statement by our Director of the Division of Research, Dr. Williams, and a further, more technical statement by Dr. Haworth, the Director of the Brookhaven National Laboratory.

Representative Price. I think it might be advisable after your statement that Mr. Floberg present the formal statement. I think it might be advisable for the committee to permit him to do it without interruption, and following his statement both you, Mr. Chairman, and Mr. Floberg will be available for questioning.

Mr. McCone. Yes, sir; I would like to reiterate information given to the committee at the authorization hearings on March 24, when I briefly referred to the fact that in August of 1958, Dr. Killian and I in a meeting concluded that an intergovernmental group should be established for the purpose of studying the whole question of high-energy accelerators, and arriving at some policy considerations which could be considered governmentwide policies. We therefore set up a technical group on which were representatives of the General Advisory Committee of the Atomic Energy Commission, and the Scientific Advisory Committee of the President. This group, under the chairmanship of Dr. Piore, worked for several months, intensively studying this problem, and submitted a report in November 1958 (see p. 527), which has been the foundation for the policies and the recommendations that we have made to you. This report was very carefully considered by the various departments of Government that were involved, and as a result the executive branch of the Government decided to recommend to the Congress that the first project recommended by the Committee be initiated at this time. This is the Stanford accelerator.

This decision was reached initially about mid-April or early April after the report had been studied and discussions held with the President. A matter of about a month followed during which time the project was given consideration by the Bureau of the Budget and the Defense Department and the AEC. There was a period in which it was not clear as to just what agency of Government would assume final responsibility for this project. It was finally decided that it would be assigned to the Atomic Energy Commission.

This was not originally expected because for several years while this project had been under study and preliminary research and investigatory work, it was supported by the Department of Defense, through the Office of Naval Research. The decision to place the responsibility in the Atomic Energy Commission was based on a determination by the Bureau of the Budget, and those within the Bureau who are concerned with Government organization matters, that the Atomic Energy Commission had considerable responsibility in this field of high-energy accelerators and a high degree of competence, and therefore it was felt that it would be best to keep this whole area more or less concentrated in the hands of one agency.

Representative PRICE. Was the study that you referred to made at the behest of the Department of Defense rather than the Commission?

Mr. MCCONE. No. The study that I referred to was made at the behest of Dr. Killian, the scientific adviser to the President, and myself, as the Chairman of the Atomic Energy Commission. We concluded that this matter was one so large that it should be approached in much the same way that the question of national policy on wind tunnels was approached 10 or 12 years ago, and ended up in a unified program for the construction of the appropriate number of properly designed and properly sized wind tunnels. Until that national policy was established various departments of Government were concerned with wind tunnels and there was evidence that there would be some duplication and therefore unnecessary expense.

As I say, the assignment of this project to the Atomic Energy Commission was not made until quite late, well after the decision was made to go forward with the project. It was for that reason that the Atomic Energy Commission was forced to make some rather concentrated last minute studies and verifications of certain estimates, and, I think, also, this accounted for some, but not all, of the delay in placing the proposed legislation in the hands of your committee.

I would like now if Mr. Floberg would proceed with his statement. I did want to have the opportunity for those opening remarks.

Representative PRICE. I would like to straighten out the time of the decision to go ahead with the project. When was the President's decision made to request authorization?

Mr. MCCONE. I cannot answer exactly. The President's decision to go forward, subject to clarification of a great many details, was made in April. As I remember it was following a meeting early in April. There were subsequent discussions and meetings which I did not attend, because at that time it was considered a Department of Defense project. There was a period between early April and the 4th of May in which the policies were formulated and finally crystallized. The first formal notice that we had of AEC responsibility was by letter which, I believe, was dated the 4th of May.

Representative PRICE. The question arises why the Joint Committee was not informed of the decision to go ahead with this until 1 day prior to the time the bill was sent up to the committee.

Mr. MCCONE. Receiving this letter on the 4th of May—and I think we had the information orally a day or two earlier than that—we questioned the manner in which the assignment was made. The reason for it was that we felt, and I took the position in several meetings with the Piore committee, and also in meetings with both Dr. Killian and the Bureau of the Budget, that this project should be aside and separate from the budget of the Atomic Energy Commission, or any of the agencies. It should be a matter of special authorizing legislation, and considered separately from the standpoint of annual appropriations. This was agreed to. However, the letter of May 4 was not abundantly clear that this was the understanding. I therefore went back to the Bureau of the Budget during the days following the receipt of that letter and finally had this point cleared up, and the matter was confirmed by an exchange of letters.

It was because of the necessity of clearing these points, plus the necessity of having the Stanford people come back for final discussion, and to have a final hearing with the Bureau of the Budget, which was held on May 12, incidentally, that we felt that we were not in a position to finally advise the Joint Committee.

Representative PRICE. Do you have a copy of the letter to which you refer?

Mr. MCCONE. Yes, I think I have copies of it here. I will supply you with this correspondence. It is here, but it would be time-consuming to take it out.

(The letters referred to follow:)

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., April 6, 1959.

Hon. MAURICE H. STANS,
Director, Bureau of the Budget.

DEAR MR. STANS: This is in connection with the question raised by Mr. Schuldt, of your staff, as to our position on the funding of the Stanford accelerator construction, in the event it is determined that this should be the responsibility of the Commission. We would have no objection to effecting a reduction of $5.5 million under our 1959 operating expense appropriation and having this amount reappropriated to our 1960 operating appropriation, thereby reducing the 1960 appropriation requests under that appropriation, so that a like amount could be added to our 1960 request under the plant acquisition and construction appropriation.

We do have a concern, however, on the impact of the balance of the construction funds and the required operating costs on our budgets for future years. If the responsobility for this project is assigned to the Atomic Energy Commission, and the initial funding of construction is carried out in the manner noted above, we would like to have your assurance that the amounts required for the project in future years will be considered entirely apart from any budgetary ceilings for the remainder of the Commission's program.

Sincerely yours,

JOHN A. MCCONE, *Chairman.*

EXECUTIVE OFFICE OF THE PRESIDENT,
BUREAU OF THE BUDGET,
Washington, D.C., May 4, 1959.

Hon. JOHN A. MCCONE,
Chairman, U.S. Atomic Energy Commission,
Washington, D.C.

MY DEAR MR. MCCONE: This is in reply to your letter of April 6, 1959, regarding the funding of the Stanford accelerator, a project recently approved by the President upon the joint recommendation of Dr. Killian, Special Assistant to the President for Science and Technology, and the Atomic Energy Commission, the Department of Defense, and the National Science Foundation.

It has now been concluded that this project should be funded, constructed, and operated by the Atomic Energy Commission, which already is responsible for most of the Government's support of high energy physics. Accordingly, there is no objection to your reprograming funds along the lines of the first paragraph of your letter.

As has been made clear in the discussions attendant upon the approval of the Stanford accelerator, it has come to be considered a national resource in a somewhat special sense, although the same may also be said of the Nation's entire high energy physics plant and program. Accordingly, in a letter to me dated April 28, 1959, Dr. Killian has proposed the creation of an interagency technical working group in high energy physics under the Federal Council for Science and Technology to consider technical problems which may arise in the construction of the Stanford accelerator and, more generally, to concern itself with the broad planning of Government programs in high energy physics and the utilization of accelerators.

With reference to the point made in the last paragraph of your letter of April 6, we recognize that the accelerator, once begun, must be provided with necessary funds for its completion, and we would expect to consider it somewhat apart from the rest of the Commission's fiscal needs, especially in its construction phase. However, I am sure that you recognize the importance for the success of the project that it be treated as an integral part of the Commission's program, beginning with the detailed planning for the project.

Dr. Killian informs me of tentative plans for the President to announce in mid-May the administration's decision to seek this authorization. It would appear desirable, therefore, for the Commission to proceed promptly with preparation of the necessary authorizing legislation for review by the Bureau of the Budget. Pending the Presidential announcement, we should avoid disclosure of the administration's plans.

Sincerely yours,

MAURICE H. STANS, *Director.*

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., May 12, 1959.

Hon. MAURICE H. STANS,
Director, Bureau of the Budget.

DEAR MR. STANS: I have your letter of May 4, 1959, regarding the Stanford accelerator and making reference to my letter of April 6, 1959, relative to the funding for that project. In your letter you state that "we recognize that the accelerator, once begun, must be provided with necessary funds for its completion, and we would expect to consider it somewhat apart from the rest of the Commission's fiscal needs, especially in its construction phase."

My letter pointed out the need for your assurance that the amounts required for this project in future years would be considered entirely apart from any budgetary ceilings for the remainder of the Commission's program. I feel that your letter provides little assurance in this regard and desire to reemphasize the importance of this point. The Stanford accelerator is a major project both for construction and operation. The effect of absorbing the project in our normal budget considerations as a part of our regular program would have serious implications on our ability to carry out even the essential projects.

Sincerely yours,

JOHN A. MCCONE, *Chairman.*

EXECUTIVE OFFICE OF THE PRESIDENT,
BUREAU OF THE BUDGET,
Washington, D.C., May 28, 1959.

Hon. JOHN A. MCCONE,
Chairman, U.S. Atomic Energy Commission,
Washington, D.C.

MY DEAR MR. MCCONE: I have your letter of May 12, 1959, regarding the Stanford accelerator and making reference to our previous correspondence on the subject.

As you point out in your letter, the Stanford accelerator is indeed a major project both for construction and operation. Inevitably the decision to commit funds of this magnitude to the Stanford accelerator will have some effect upon the availability of funds for other governmental purposes, whether within or outside the Commission's program. In this sense we cannot, from the standpoint of sound financial management, consider this project or any other project "entirely apart" from the Government's total fiscal needs.

On the other hand, it is clearly not our intention to expect the Commission to absorb the cost of the project in its normal budget. I visualize that in arriving at annual ceilings and budget allowances, the fund requirements for this project will be considered separately and will be assigned a special priority. This should meet your point entirely.

Sincerely yours,

MAURICE H. STANS, *Director.*

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Representative PRICE. The delay in getting word to the committee until you were just ready to submit an authorization proposal had nothing to do with the uncertainties on the part of the Commission as to the technical feasibility of the project.

Mr. MCCONE. No, there was no concern. There was a concern, during that period, as to the estimated cost of the project, but there was no concern about the technical feasibility.

Representative PRICE. The concern was budgetwise, rather than any technical problem.

Mr. MCCONE. That is right. I think the testimony will bring out the fact that there was some $10 million difference in the estimates, and this was one of the things we wanted to go into. The delays, if there were delays, were due to the fact that this project was assigned at a very late date. In accepting it, the Commission wanted to be sure that we at least had a pretty good look at the work that had gone on before, and secondly, that we were in complete agreement with the Bureau of the Budget concerning the future funding of this project, which is a very large item. It was for that reason that we were a little cautious for a few days to be sure that we had complete understanding.

Representative WESTLAND. Mr. Chairman, it seems to me that the committee is somewhat in agreement with the chairman of the Atomic Energy Commission, that we received this bill just at a time when the committee had finished rather laborious consideration of an authorization bill. The first impression that I had, at least, I think other members of the committee had, too, was that this $105 million should be included in that authorization bill without any further consideration. Then we decided to take this up separately.

Representative PRICE. I think the main reason it was decided to take it up separately was due to the magnitude of the project, and a desire on the part of the committee, because it did amount to such a large figure, to give it rather close scrutiny before giving final approval.

Mr. MCCONE. It had been my position throughout the discussions for many, many months that this project, first because of its size, and secondly because of its very great importance, should be considered as a separate and independent piece of authorizing legislation.

Representative PRICE. That was the position of the majority of the committee, also.

Mr. MCCONE. That had been my position.

Representative PRICE. We are getting into an area now where these machines are required and most of us recognize the importance of the machines, but one machine costs almost as much as we have invested in all the other accelerators up to this time in the whole program.

Mr. MCCONE. That is correct. Furthermore, quite aside from the capital cost, there is a very substantial annual operating cost that we have to look at.

Representative PRICE. What do you estimate the operating cost will be?

Mr. MCCONE. It is estimated at $15 million.

Representative PRICE. That is the annual operating cost?

Mr. McCONE. Yes, sir. I am not the least bit blind to the fact that machines of this kind, in addition to the estimated operating cost, usually have incremental improvements and additional expenditures which become absolutely necessary. You are familiar with that. I think the bill will probably be somewhat higher.

Representative PRICE. I think we ought to get on with the testimony now so that we can get a clear picture of what the machine is, and the requirements for it in the program.

Mr. Floberg, will you proceed?

STATEMENT OF JOHN F. FLOBERG, COMMISSIONER, U.S. ATOMIC ENERGY COMMISSION

Mr. FLOBERG. Mr. Chairman, my name is John F. Floberg, and I have a prepared statement to read to the committee.

I am pleased to be here to day to explain to you the needs that justify the Commission's request to the Congress for authorizing legislation for the construction of a high-energy electron linear accelerator at Stanford University in Palo Alto, Calif. I trust that we will be able to explain to the Joint Committee on Atomic Energy that this project has reached the stage where the Congress should authorize the construction of the accelerator and its associated facilities.

I would first like to review the events that led up to the decision to proceed with this project.

Last July, it became apparent to the senior executives in the Atomic Energy Commission, the National Science Foundation, and the Department of Defense that an exhaustive review of the high energy accelerator physics program of the United States should be made.

It was clear that the Federal Government had a real responsibility to examine this program because continued world leadership by the United States in this field had to be weighed against the extraordinarily high cost of construction and operation of high energy accelerators. Most of the financial support in the field of high energy accelerator construction and operation comes from the Federal Government. It was, therefore, deemed to be essential that an evaluation be made of the impact that increased Federal support for high energy physics might have on the Federal support for other areas of science.

The National Science Foundation for the last several years has been studying and reviewing the high energy research program of the United States at the request of the Atomic Energy Commission and the Department of Defense. In 1956, the National Science Foundation appointed a group of outstanding scientists to an ad hoc panel under the chairmanship of Dr. Leland J. Haworth, Director of the AEC Brookhaven National Laboratory. In October 1956 this panel prepared an overall report on high energy accelerators (see p. 235).

A study of the feasibility of constructing a 2-mile long linear accelerator had been started by Stanford physicists early in 1954, and initial proposals were submitted in 1957 (see p. 283) to the National Science Foundation, the Atomic Energy Commission, and the Department of Defense.

The Commission sent the proposal to several outstanding scientists for review. These scientists were almost unanimous in recommending that support be given to the Stanford proposal. Many of the scien-

supporting accelerator research and radio-frequency power tube development at Stanford University in particular. Prior, however, to announcing his decision on May 14, the President decided that the Stanford project should be administered by the AEC because of our extensive experience in the construction and operation of accelerators in the multi-Bev. range.

While the AEC did not actively seek the responsibility for this undertaking, I express the views of my colleagues when I say that we accept this great basic research undertaking with a sincere appreciation of the importance of the accelerator to our national scientific program. The President in his May 14 address at the symposium on basic research pointed out that the Stanford accelerator was of vital importance, but because of the cost, it must become a Federal responsibility.

(President Eisenhower's address referred to above follows:)

(Text of the address by the President at the Symposium on Basic Research, sponsored by the National Academy of Sciences, the American Association for the Advancement of Science, and the Alfred P. Sloan Foundation, held at the Waldorf-Astoria Hotel, New York City, May 14, 1959, as actually delivered)

SCIENCE: HAND MAIDEN OF FREEDOM

Dr. Bronk, Mr. Sloan, fellow innocents in the field of science, ladies and gentlemen, it is a great privilege to be present at this meeting with so many Americans actively interested in basic science. Equally it is for me a unique experience. I have no professional competence in searching out nature's secrets and out of my own knowledge I can make no professional suggestions on the substance of science to which you could possibly accord the slightest validity.

Nevertheless, I hope that in a fairly long life, punctuated here and there by promotions of various types, that I have not reached the state of exalted position and complete uselessness that was acheieved by one of the hunting dogs I heard about, trained by a northern woodsman.

Their master, who had long enjoyed a warm acquaintanceship with a university community, had the habit of naming his dogs for faculty members that he admired. But when a few wives became a little indignant over the practice, he decided to name his dogs for various academic ranks—instructor, assistant, and professor, and so on.

One hunting season, a man from Chicago hired for $2.50 a day a dog he liked very much. And the following year, asking for the same dog, was told the price would be $5 a day. When he protested the steep inflation and insisted that it was the same dog, the owner agreed, but said that the dog had been promoted to assistant professor and was now worth the added money.

Well, next hunting season, the price jumped to $7.50 because the dog had then achieved the rank of associate professor. And the year after, it was raised to $10, the reason being that the well-trained canine had reached the noble status of full professor.

The following year, when the hunter returned to rent the same dog, he was turned down. "Why not?" demanded the hunter insistently. "Well, I'll tell you," said the old woodsman, "I can't let you have him at any price. This spring we gave him another promotion and made him the president of the college. Now all he does is sit around and howl and bark, and he ain't worth shooting."

Now, even though my scientific education is limited, I think there may be some usefulness in considering together certain aspects of the relation of Government to science and the conditions under which the work of scientists and scholars will best flourish.

In our lifetime greater advances have probably taken place in science and technology than in all prior history, and these advances have profoundly affected, and will continue to affect, our manner of living. These advances and changes have also had a profound effect on Government and on national policy. In my public service I have found myself increasingly involved in dealing with problems and policies affected by the growth and impact of science and technology. Out

tists, however, pointed out that while support should be given to Stanford, it should not be done at the expense of other areas of research. To clarify the relation of the Stanford proposal to the overall research picture, the National Science Foundation panel was reconstituted in 1958 to review the Stanford proposal. On September 11, 1958, in an amendment to its 1956 report, the NSF panel recommended that favorable consideration be given to the Stanford proposal. Mr. Chairman, in view of their specific consideration of the Stanford proposal, you may wish to have the 1956 panel report and the 1958 amendment thereto inserted in the record of these hearings. (See p. 235 and p. 251.)

The recommendations of the National Science Foundation panel were reviewed extensively by a special panel composed of members of the General Advisory Committee to the Atomic Energy Commission, and members of the President's Science Advisory Committee. In late November 1958, the SAC–GAC panel, chaired by Dr. Emanuel Piore of the President's Science Advisory Committee, recommended to the President's Science Adviser that the proposal of Stanford University to construct an electron linear accelerator, modified to operate at 10 to 15 billion electron volts, be accepted.

The recommendations of the SAC–GAC panel on "U.S. Policy and Actions in High Energy Accelerator Physics" are broad and far-reaching in nature. Therefore, I suggest that you may desire that they be reproduced in the record of these hearings.

Representative PRICE. Without objection, the reports on the project will be included in the record, if it is possible for you to supply those reports.

Mr. FLOBERG. Yes; we shall supply it, sir.

(The data referred to will be found in app. 2, p. 527.)

Mr. FLOBERG. The General Advisory Committee to the U.S. Atomic Energy Commission has approved the Panel report and agreed with its recommendations and conclusions. They noted, however, that the magnitude of Federal expenditure for high-energy physics is reaching such a high level that it is important to insure that progress in this field does not interfere with the building up and orderly growth of other areas of basic science. This is an important point and one that all of us must be mindful of during the course of future considerations of research programs and budgets.

The Commission considered the SAC–GAC Panel report last December. The Chairman of the AEC participated in the subsequent discussions on this matter with the President's Science Advisory Committee and later with the President, which discussions ultimately led to the decision by the President to seek congressional authorization to construct an electron linear accelerator at Stanford University capable of providing generous quantities of 10–15 Bev. electrons.

When Mr. McCone appeared before this committee during the authorization hearings on the fiscal year 1960 construction program on March 24, he brought you up to date on the then current status of the review of this project. It appeared possible at that time that the Department of Defense might be the agency that would build this accelerator, not because of a particular military significance of the machine, but because of the DOD's history of supporting high-energy physics in general and of the Office of Naval Research's history of

vigorous, and rapidly growing society, the uninformed often referred in slurring terms to what we called the impractical scholar. Fortunately, we have come far from that point. We have done much in overcoming this misunderstanding. We have learned that the apparently visionary researcher is likely to produce unexpectedly practical results. Witness the work of such scientists as Faraday, Pasteur, Gibbs, Einstein, Fermi, and Von Neuman.

Basic science, of course, is the essential underpinning of applied research and development. It represents the frontier where exploration and discovery begin. Moreover, achievements in basic research, adding as they do to man's fundamental understanding, have a quality of universality that goes beyond any limited or local application or limitation of time. Eventually, those discoveries benefit all mankind.

Today, the American record in basic research is becoming no less brilliant than in applied science. The past 50 years have seen a remarkable growth of graduate schools of science and other types of research institutions. Since World War II scientists working in the United States have won more than half of all the Nobel prizes awarded in the physical sciences. If we can continue to cultivate our strength and achievement in this field of basic research, we shall greatly enhance our capacity to defend ourselves, and simultaneously advance our economic and cultural strength.

Vigilance and effort are required.

I am told that fewer than 30,000 scientists and engineers, or less than two one-hundredths of 1 percent of our population, are now engaged in basic research. Only about 4 percent of our scientists and engineers are engaged in basic research. Educators and scientists warn us that we need to step up this effort, if we are to move forward on the broadest scientific front.

And I think, my friends, this has to be a studied effort. Although we have long known that necessity is the mother of invention, we cannot depend upon accident to bring about these advances that we need.

All of us know the old story of finding that cooked meat was much better than raw meat, when the ancient Chinese had his barn burned down and a bunch of pigs were in it. Well, he found out about crackling, that it was very good.

Another accident, and for this story I am indebted to a friend of mine here who is far too shy and modest to want me to identify him. And it was about a hearing aid, Mr. Sloan. This man needed a hearing aid, and he went to the store and he found that the cheapest one was $200 and when they ran up to $800, he decided this was clear outside his pocketbook range, so he decided to make one himself. Which he did. And he worked it with pretty good effect.

Well, finally, a man said to him, "Now tell me, Bill, does this thing really work?"

He says, "Of course not, but it makes everybody talk louder."

We cannot afford to look for our advances in this kind of result, even if the result was, in this case, only psychological.

In seeking out and educating the necessary talent we need to insure, as we have done in the past, that the search for fundamental knowledge can best be undertaken in areas and in ways determined primarily by the scientific community itself. We reject a philosophy that emphasizes more dependence upon a centralized approach and direction. Regimented research would be, for us, catastrophe.

The progress and growth of America depends upon many qualities of our people. Clearly these include curiosity, imagination, educational preparedness and tireless stamina. Without these we could not be a people of true creative genius. We must search out the talented individual and cultivate in all American life a heightened appreciation of the importance of excellence and high standards; not only in specialized fields, but in individual dimensions of diversity as well.

It is very much worth noting, I believe, Tocqueville's comment of 125 years ago in some notes just published for the first time, that what makes the American such an intelligent citizen is that he does a little of everything. This he thought was an important reason for superiority of the American in the ordinary business of life and the government of society.

But while today we require a high degree of specialization, it remains vitally important for the specialist in every field, to understand that his first responsibility to himself and to his country is to be a good citizen.

Above all, the specialist must comprehend how his own work fits in effectively in promoting the national welfare.

of this experience in dealing with these matters and my close and cordial relationships with increasing numbers of scientists and engineers arise such observations as I shall make tonight.

First, I must congratulate the Sloan Foundation, the National Academy of Sciences, and the American Association for the Advancement of Science, for sponsoring this conference on basic research. The Nation cannot help but feel a profound satisfaction in seeing so many leading representatives of education, industry, and Government participating in a symposium concerned with such a vital effort.

And I derive special satisfaction from the fact that this conference is sponsored by private interests. Too often we have tended to look unduly to the Federal Government for initiative and support in a multitude of activities, among them scientific research. We must recognize the possibility that the Federal Government, with its vast resources and its increasing dependence upon science, could largely preempt the field or blunt private initiative and individual opportunity. This we must never permit.

Too much dependence upon the Federal Government may be easy, but too long practiced it can become a dangerous habit.

Yet, Government's role in research and its responsibility for advancing science must be large and there must be a persistent partnership between Government effort and private effort. Our science and technology are the cornerstone of American security, American welfare, and our program for a just peace. For the Government to neglect this would be folly. But the strength, growth, and vitality of our science and engineering, as in every other productive enterprise, hinge primarily upon the efforts of private individuals.

Private institutions, foundations, colleges and universities, professional societies and industry, as well as all levels of government, have a vital role to play in promoting individual leadership and in striving for excellence and the achievements of a high level of creative activity. Thus is created increased opportunity to pioneer, to initiate, and to explore untrodden areas.

* * *

Now, through the growth of scientific knowledge we in America have profited immeasurably.

We have done so because we are free.

Freedom is the central concept of our society, and this freedom of each to try, to fail, and to try again is the mainspring of our progress.

Freedom is both cause and effect; by sustaining it we preserve the essential condition of learning, while the benefits that flow from knowledge work to keep us free.

As we have long known, freedom must be earned and protected every day by everyone of us. Freedom bestows on us the priceless gift of opportunity—if we neglect our opportunities we shall certainly lose our freedom.

Our immediate task—America's first responsibility—is to see that freedom is not lost through ignorance, complacency, or lack of vigilance. And this applies to our domestic problems and to those abroad. It is important that in our daily lives at home we so conduct ourselves in politics, in business, in education, that liberty is not impaired. Equally we must be alert to our duty of assuring that neither we, or other free nations, succumb to an ideological system dedicated to aggressive force and governed by fear.

That we succeed in this task—that we successfully preserve freedom amidst an uneasy climate of disquiet and tension—depends more than ever upon the readiness of each of us to advance American science and engineering.

It is in this strong conviction that I particularly stress the freedom of the scholar and the researcher.

* * *

From the very outset of our Republic, the Government of the United States has sought to encourage science and learning. Our early statesmen, Washington, Jefferson, Franklin, and Adams, all sought to find ways by which the new Republic could sponsor learning and promote the progress of science and the useful arts.

The founders of the American political system clearly believed that the secrets of nature must be better known so that they might be used to advance the welfare of all our people.

But while, under the stimulus of practical need, the application of science to problems of production and growth became accepted practice in our young,

Twenty years ago, Federal support of science was about $100 million annually. Today, this annual investment, by the Federal Government, in applied and basic research, together with pilot development, has grown to over $5 billion. A large fraction of these Federal funds is spent in laboratories owned and operated by private groups. Much of this expenditure is to meet the current and practical needs of the Federal Government. The size of these Federal expenditures and the policies and practices of the Federal Government inevitably have a substantial effect on the Nation's private scientific institutions. But again we remind ourselves that the whole program would be self-defeating if it were allowed to limit the freedom of its own research.

During recent months we have made many moves to strengthen the management of your Government's scientific activities. These include a number of advisory committees and several new legally authorized agencies. All of them are designed to point up and enhance and coordinate scientific research.

And now, let me cite one example which illustrates an appropriate way for the Federal Government to further our basic scientific research effort. Incidentally, when I quote the cost, George Humphrey will hurt.

Recently the General Advisory Committee to the Atomic Energy Commission and my Science Advisory Committee, under the chairmanship of Dr. Killian, appointed a special panel of scientists to undertake a comprehensive review of the Federal Government's participation in the high-energy accelerator physics field.

On the basis of this report, I am recommending to the Congress that the Federal Government finance the construction as a national facility of a large new electron linear accelerator. Physicists consider the project, which has been sponsored by Stanford University, to be of vital importance. Moreover, they believe it promises to make valuable contributions to our understanding in a field in which the United States already is strong, and in which we must maintain our progress. Because of the cost, such a project must become a Federal responsibility. This proposed national facility, which will be by far the largest of its kind ever built—a machine 2 miles long—has the endorsement of the interested Government agencies—including the Treasury. Construction of the accelerator will take 6 years, at an overall cost of approximately $100 million.

* * *

By such means the Government labors to advance our scientific knowledge and to further the free use of science for healing, for enriching life and freeing the spirit.

In emphasizing these objectives and needs, I am deeply aware that they are inseparable from the broader goal of enriching the quality of our society and enhancing the excellence of our intellectual life.

We cannot improve science and engineering education without strengthening education of all kinds. America must educate all the varied talents of our citizens to the limit of their abilities.

Here what we seek is talent of the first rank.

We do not ask of a man his race, his color, his religion.

In the field of intellectual exploration, true freedom can and must be practiced.

The dignity of man is enhanced by the dignity and freedom of learning. How well the learning is accomplished depends upon the competence and devotion of those to whom the training is entrusted: the teachers and educators at all levels, everywhere, throughout our land.

So let us cultivate more respect for learning, for intellectual achievement, for appreciation of the arts and humanities. Let us assign true education a top place among our national goals. This means that we must be willing to match our increasing investments in material resources with increasing investments in men.

For my part I have long urged and supported the idea that there should be established a hall of fame for the arts and sciences. Membership would be an honor to which every American boy and girl could aspire.

Talent and quality are vital to our national strength—they are the ingredients needed to carry us onward and upward to higher peaks of achievement in science as well as in the nonmaterial world of the mind and the spirit.

Science, great as it is, remains always the servant and the handmaiden of freedom. And a free science will ever be one of the most effective tools through which man will eventually bring to realization his age-old aspiration for an abundant life, with peace and justice for all.

Thank you very much indeed.

Mr. FLOBERG. The Stanford linear accelerator will provide an intense electron beam of 10–15 Bev energy, by far the highest energy electron beam in the world. The accelerator will be designed in such a way that at a later date, the beam energy could be increased to about 45 Bev should the situation in high energy physics so warrant and should the Congress authorize such an extension.

The Stanford University proposal to construct and operate this accelerator has had detailed review by the best talents which are available in this country. The endorsements which have been given to the proposal were based in a large part on the recognized outstanding competence of the technical staff at Stanford University. Their results have been impressive, and we are fortunate to have a rare combination of scientific talent and a unique machine.

The proposed accelerator will not require development of new basic components. I am informed that, in order to build a higher energy accelerator, it is necessary only to reproduce a longer version of a machine of the type already in operation. The existing linear machine at Stanford has been successfully operated for several years with energies as high as 730 Mev and will reach about 1.0 Bev upon completion of modifications currently underway. The scientists at Stanford are ready and eager to proceed with this project which has already reached a highly developed stage.

The project will be established as a national research facility to be used not only by scientists from Stanford University, but from many other institutions in the United States. Indeed, the facility will, without question, have worldwide scientific significance in research in high energy physics and should present unique opportunities for a high degree of international collaboration and cooperation.

The best current estimate of the total construction cost for the Stanford project is $105 million. In addition, $18 million would be spent during the 6-year construction period on research and development activities directly related to the construction phase of the accelerator. The major part of the research and development effort will go toward improvement and engineering refinement of the klystron and accelerator components to the stage where detailed specifications can be written. Although these components have been proved on a laboratory scale and have been used in operating machines, some development work must be done before they can be efficiently designed for this large-scale application.

I would like to point out that once this machine is placed in operation, the annual operating cost will be about $15 million. Because of the long leadtime required for the development of research apparatus and the need to build the research program in advance of initial operation, we anticipate that the research-oriented operating program will be started about 2 or 3 years prior to the final completion of the accelerator.

The $105 million estimate of the construction cost is based on the detailed experience of Stanford University in the fabrication and operation of existing accelerators. The proposal was reviewed by an independent engineering firm with special competence in accelerator design and engineering, the William Brobeck Associates (see p. 427 for a copy of the review), and has been further reviewed by our own construction and engineering staff.

The Commission and its proposed contractor, Stanford University, feel that the $105 million is a sound estimate of the construction cost for this machine. In view of the 6 years required to complete the facility, however, and the many factors which could possibly arise, we feel that it would be appropriate for the Congress to authorize an expenditure of an additional 25 percent should circumstances now unforeseen require it.

Mr. Chairman, in order to see that your committee has all the pertinent facts before it, I have asked Dr. John H. Williams, our Director of Research, to present more details of the proposal to you, including the plan for operating the machine so that maximum participation by scientists from other laboratories can be obtained.

He will be assisted in this task by Dr. Leland J. Haworth, Director of the AEC Brookhaven National laboratory. Dr. Haworth will present the reasons which prompted the review panels to recommend this accelerator be approved.

Dr. Williams will also be assisted by Prof. Edward Ginzton of Stanford University. Professor Ginzton will provide your committee with pertinent details of the construction of the accelerator.

Representative PRICE. Before Dr. Williams begins the testimony, I would like to ask one or two questions.

In my request for the reports you mentioned in your letter I also include the report that you referred to in this final paragraph on page 2 of your statement.

Mr. FLOBERG. Yes, sir. Those will be made available to you. I have them here. (See pp. 235 and 251 for NSF 1956 and 1958 panel reports.)

Representative PRICE. And also the second to last paragraph on page 3 of your statement.

Mr. FLOBERG. Yes, sir; those will be furnished to the reporter.

(The information referred to follows:)

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., July 22, 1959.

Mr. JAMES T. RAMEY,
Executive Director,
Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. RAMEY: During the recent authorization hearings on the Stanford accelerator, Mr. Ted Brown of your staff discussed with Dr. McDaniel the availability of any recommendations of the General Advisory Committee concerning the accelerator.

I am attaching for the information of the Joint Committee extracts of the comments of the GAC pertaining to the Stanford accelerator made during its 61st and 64th meetings. I trust that the attachments will provide you with the necessary information.

Sincerely yours,

A. R. LUEDECKE, *General Manager.*

GENERAL ADVISORY COMMITTEE TO THE
U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., February 3, 1959.

Mr. JOHN A. MCCONE,
Chairman, U.S. Atomic Energy Commission,
Washington, D.C.

DEAR MR. MCCONE:

* * * * * * *

(2) *SAC–GAC panel on high energy accelerators, national policy*

The General Advisory Committee approves the report of the special panel entitled "U.S. Policy and Actions in High Energy Accelerator Physics," as an excellent statement of the current situation and of the optimum U.S. program. The magnitude of the budget reaches a level, however, which would be considered a disproportionate emphasis in high energy nuclear physics unless budgets for other areas of basic research are substantially expanded. While the unusually high cost of high energy accelerators is recognized, some other areas of science are of at least as great importance to the broad aspects of atomic energy, and care must be taken to give adequate support and emphasis to these areas.

* * * * * * *

Respectfully submitted.

WARREN C. JOHNSON, *Chairman.*

GENERAL ADVISORY COMMITTEE TO THE
U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., May 15, 1959.

Mr. JOHN A. MCCONE,
Chairman, U.S. Atomic Energy Commission,
Washington, D.C.

DEAR MR. MCCONE:

* * * * * * *

(6) *Report of SAC–GAC panel entitled "U.S. Policy and Actions in High Energy Accelerated Physics"*

This report was approved by the GAC at the January 5–7, 1959, meeting of the Committee. The Chairman of the GAC advised the Chairman of the AEC, in his letter of February 3, of this action and included a supplementary statement of warning of the possibility of creating a disproportionate emphasis in high energy nuclear physics relative to other areas of science.

Recently, we were informed that the President's Science Advisory Committee proposed to release the report of the panel to the public after minor modifications in the recommendations had been made relative to the MURA and Oak Ridge National Laboratory programs. The reasons for these modifications are, that since the final report of the panel was submitted, (1) MURA has withdrawn its proposal, and (2) Oak Ridge is in process of restudying its proposal.

The GAC approves these modifications and, in addition, has prepared the following statement to be used in the release of the report, in the event it should be decided that the report should carry the names of all the members of the Committee:

"The General Advisory Committee to the U.S. Atomic Energy Commission approves the report entitled 'U.S. Policy and Actions in High Energy Accelerator Physics,' and agrees with its recommendations and conclusions. We note, however, that the magnitude of Federal expenditure for high energy physics is reaching such a high level that it is important to insure that progress in this field does not interfere with the building up and orderly growth of other areas of basic science."

* * * * * * *

Respectfully submitted.

WARREN C. JOHNSON, *Chairman.*

Representative PRICE. I think perhaps Mr. McCone can answer this question because it has to do with a matter of policy at the present and in the future, and one, I think, must be resolved on a more or less permanent basis. In testimony before the Joint Committee on the 1960 authorization bill, the Commission stated that a policy should be established prior to the authorization of facility construction at the campuses of private universities. Has such a policy been established on this matter, and if so, what is it and how is it being applied to the Stanford project?

Mr. McCone. No, Mr. Chairman. At the present time the governmental policy has not firmly been established in connection with the Federal Government furnishing facilities at private universities or at State universities. When I mentioned facilities, and in the context of that statement which you referred to, I was thinking of facilities of a type which had more universal application to research or to education purposes than a specialized machine of this type. I feel that it is very important from the standpoint of the advancement of science and the future of the departments of Government which are so dependent upon the advancement of science, that we carefully study and reach an agreed conclusion as to just what role the Federal Government should play in supplying these essential laboratory facilities which are in effect facilities for the final stages of advanced education.

If it is impossible for private institutions or State institutions to supply these facilities, then the Federal Government has to give careful consideration to doing so. I do not, however, think that a single department of the Government should launch out on a program in the absence of an overall policy. Because of that feeling, I have appealed to other departments of Government to come together and to establish such policies. I do not look upon this facility, however, as falling in the category of the type of facility that has a universal application to research and to the advanced training, although it does to an extent have that application. This, however, is a highly advanced research tool which is to be built at Stanford University, assuming your authorization, for the reasons that Mr. Floberg mentioned in his statement and which will be expanded upon by Dr. Williams and Dr. Haworth.

Representative Price. Once you enter into the policy in individual cases of supporting research tools on the campuses of private institutions, doesn't that more or less set a precedent so that you could then justify the construction of a laboratory on a private campus?

Mr. McCone. No; I do not think that the building of this research tool on a private campus would establish a precedent for the building by the Federal Government of a laboratory which had more universal application in the field of science than does this facility.

Representative Price. I am not arguing against the policy because I personally might see the advantage to the Government in participating in a laboratory on a private campus.

Mr. McCone. I am not arguing against it, either, Mr. Chairman. I think that probably your staff noted a paragraph in a speech I made at Notre Dame University in which I supported the idea. But I support it only as a part of an agreed policy. I don't think it should be done in a haphazard manner.

(Correspondence on this matter follows:)

June 12, 1959.

Mr. John A. McCone,
Chairman, U.S. Atomic Energy Commission,
Washington, D.C.

Dear Mr. McCone: During the course of recent hearings by the Joint Committee on the AEC authorization bill, a policy question arose regarding the advisability of including as a line item in the bill a proposed radiation chemistry building at Notre Dame. At the committee's hearing on May 8, you made the following statement with regard to this matter:

"I think that this is a very important policy question. Here you plan to build on the campus of a private university a chemistry building. I think until a decision is reached for the Federal Government to go into private universities and build buildings here and there we should not do it. This is in no way to cast any shadow on the very valuable work in the field of radiation chemistry that is done at Notre Dame. If we are going to do a thing like this there ought to be a policy established."

In an address at the University of Notre Dame on June 7, you made reference to the radiation chemistry program at Notre Dame, describing this program as one of the "pillars of our research program." You then went on to state:

"I can foresee a new, fine laboratory on this campus which will be devoted exclusively to basic research in radiation chemistry. Your faculty feels it essential. Ways will be found to provide it. Personally, I feel it is within the province of the Government to help universities with their scientific work by assisting them to acquire facilities essential to both Government and university needs. I am an advocate of these programs. I believe that our progress in atomic energy, in defense, and in the space age require the best in the university. This is the starting point, as I have said, of the search for new scientific knowledge."

In light of your testimony before the committee regarding the policy problems involved in going forward with the Notre Dame project as a line item, the committee did not include this project in the current AEC authorization bill. It appears to be agreed, however, that there is a genuine need in the physical research program for such a laboratory and that similar needs will continue to arise in the future in connection with research programs at other universities.

For this reason, it would appear desirable for the Commission to give this policy question serious consideration with a view to developing means for meeting these needs as they arise in the future. I would appreciate being kept informed as to the progress which is being made on a resolution of this question by the Commission.

Sincerely yours,

MELVIN PRICE,
Chairman, Subcommittee on Research and Development.

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., July 8, 1959.

Hon. MELVIN PRICE,
Chairman, Subcommittee on Research and Development, Joint Committee on Atomic Energy, Congress of the United States

DEAR MR. PRICE: Your letter of June 12, 1959, cites statements made by the Chairman before the Joint Committee on Atomic Energy on May 8, 1959, and in an address at Notre Dame on June 7, 1959, regarding a chemistry building at Notre Dame, and points out the desirability of the Commission giving serious consideration to the policy question of construction of facilities by the Federal Government on the campuses of private universities. It further requests being kept informed of the progress made on resolution of this policy question.

This is to advise you that the Commission has this policy question under study, and will inform you of the conclusions and results of such study upon its completion.

Sincerely yours,

A. R. LUEDECKE, *General Manager.*

Representative PRICE. I think I would agree with the chairman. I am trying to bring out the fact that sometimes it might be to the advantage of the Government to support such a project, even though the physical structure might rest on the grounds of a private institution.

Mr. MCCONE. That is right. I think we are in agreement. I am determined as far as I can have a voice to crystallize the policy in this area.

Representative PRICE. What arrangements are planned for the assignment of responsibilities for the various phases of the architectural, engineering, and construction work for this proposed project? For

example, is it planned that the Commission will assume responsibility for contracting directly for certain phases of the work and Stanford will assume responsibility for contracting for other items? How does the plan for the arrangement of this project compare with the Commission's experience on other large construction projects?

Mr. FLOBERG. The answer to your question, Mr. Chairman, is that the arrangements are not yet firm with Stanford University and they are still in the process of negotiation. The degree to which assignment of responsibility will be made to Stanford and the degree to which it will be retained by the Commission is now being worked out with Stanford, and we will hope to have an answer to that question in the relatively near future.

Mr. RAMEY. What are the alternatives being considered?

Mr. FLOBERG. The entire spectrum could be considered as available. In no case has the Commission considered, even though it is theoretically possible, that it would retain the direct responsibility for building the machine itself. The obvious minimum in a case like this is to have the best qualified people do both the architectural work and construction work on the actual machine.

The only question that really must be resolved is the conventional facilities that surround or are associated with the machine, and the degree to which this should be turned over to Stanford as a prime contractor, totally responsible to deliver in effect a turnkey project, or the degree to which the Commission should retain the control of the supervision of the construction of roads and conventional buildings is still something that we are threshing around.

Mr. RAMEY. The Commission has had a great deal of experience in this sort of thing and a lot depends on the qualifications and experience of the prime contractor and whether they have ever handled large construction projects.

Mr. FLOBERG. That is obviously a true statement. The university has had substantial experience and we will just examine for ourselves whether we think this is the proper kind of arrangement to make with them or whether we should go along with one of our more conventional and conservative past lines of approach.

Representative PRICE. Mr. Floberg, the language of section 2 of the bill is somewhat misleading to me. I will ask Mr. Toll to develop that.

Mr. TOLL. Mr. Floberg, section 2 of the bill as proposed by the Commission provides that the AEC is authorized to start the project only if the estimated cost at that time does not exceed by more than 25 percent the estimated cost set forth in the bill here of $105 million. When will the Commission start this project?

Mr. FLOBERG. I would have thought that word referred to the physical commencement of construction and not just the commencement of architectural-engineering work.

Mr. TOLL. The point, as I understand it, and I might be wrong, is that once the project is started this 25 percent limitation no longer applies.

You say in your statement that in view of the 6 years required it might be at the end of 6 years that the costs might be up to $200 million.

Mr. FLOBERG. That is not what was in mind here. The 6 years referred to the total period of construction and the 25 percent is a

typical contingency allowance that is made in public works projects that we submit to you from time to time. There is nothing remarkable about having the 25-percent expansion factor in there. It is not intended that we have a 25-percent margin at the time of construction and then a 100-percent margin at the time of completion. That was not intended at all. If there is any confusion about the language in the bill, it ought to be clarified.

Mr. TOLL. This is similar to limitations in the ordinary authorization bill except that some of them are only 10 or 15 percent.

Mr. FLOBERG. It depends on projects; that is true.

Representative PRICE. As I read your language, you are anticipating that there will be an escalation in costs or there could be over a period of 6 years and you are suggesting that future consideration bear that in mind to increase the authorization figure.

Mr. FLOBERG. Not to increase the authorization figure; it is to increase appropriations. We are authorized here to undertake the construction, Mr. Price, if, say, a year from now when the preliminary design work has been done, it turns out that the then current estimate is not $105 million but, let us say, $115 million. Then we are authorized to go ahead and start turning dirt. It could be that actual figure. We think we have given you the best figure that is available to us as an estimate of cost.

As you know, the history of accelerators is not too encouraging that the final costs will be what the initial estimate has been.

Representative PRICE. Some have been 100 percent greater than the estimate.

Mr. FLOBERG. Some of them have been pretty wild, there is no doubt about that.

Senator BENNETT. Is it your impression that when this necessary preliminary engineering and architectural and design work has been done that you will at that time be able to enter into a firm contract which can fix your costs so that with this margin of 25 percent from that point on you will be safe?

Mr. FLOBERG. I don't know if you mean a fixed-price contract, Senator.

Senator BENNETT. I assume you are going to ask for bids. Bids will be submitted, and one bid will be accepted.

Mr. FLOBERG. The prime contractor, whoever that may be, will do that very thing.

Senator BENNETT. So from your point of view, after that prime contract has been executed with the prime contractor you should know exactly what your cost is going to be.

Mr. FLOBERG. It may be that the prime contractor will have to protect himself because the subcontracts will not all be made the first day that construction begins. They will be stretched out over a period of years. While we will have a much firmer fix on it without any question, Senator, I can't say that a year from today we will have a final picture on what the cost of this project will be.

Representative PRICE. As a matter of fact, when you reach this point, and you find out that the project is going to far exceed the authorized amount, there is only one course to follow, and that is to come back to Congress to increase the authorization.

Mr. FLOBERG. That is precisely correct.

Senator BENNETT. With respect to your conventional facilities, there ought to be enough experience so that your prime contractor can give you a fixed price.

Mr. FLOBERG. I think that is a fair statement.

Senator BENNETT. So the only area of uncertainty would probably be in the erection of the accelerator machine itself.

Mr. FLOBERG. Yes, sir; I think that is true. I think we ought to have a very firm fix on the conventional facilities, including even the tunnel.

Senator BENNETT. I would think so. They are all truly conventional in their aspects, and the people who are in the business of offering contracts for the construction of that kind of facility have had ample experience, and most of their work is done on the basis of final fixed quotations which are translated into fixed contracts and they must live up to them.

Mr. FLOBERG. The uncertainties will be in the highly technical part of this facility.

Representative WESTLAND. Does the Federal Government have any investment in this project at the present time?

Mr. FLOBERG. Only in the sense that we have spent time on the analysis and study of it as far as this particular project is concerned. As far as the klystron tubes are concerned, the Federal Government has participated financially in the development of those tubes. This has been done through the Office of Naval Research. These particular klystron tubes are the foundation for the technical part of this facility.

Representative WESTLAND. I realize there might have been Federal support of research and development in an area like this. Insofar as this specific project is concerned, you say there is no Federal money invested in it at the present time?

Mr. FLOBERG. We did hire the Brobeck firm to do an engineering study on the cost estimates, and we have done some core drillings. In that sense we have spent money on the project. There is no Federal investment in physical facilities because there are no physical facilities as yet, and Stanford University owns the real estate.

Representative WESTLAND. Let me ask you this: Is this accelerator designed to be built at any place or only on the Stanford University campus? For example, could it be built in Louisiana?

Mr. FLOBERG. I think the answer to that question is, it could only be built wherever the particular people who are designing it would want to build it, because they are the only group in the scientific community qualified to design it. So while there is nothing peculiar about central California as compared to Louisiana climatically or otherwise, the fact is that you are going to have to put this facility at the place where the people use it.

Representative WESTLAND. I certainly understand that. You cannot have it built someplace and have no one use it. I was wondering whether the design for this accelerator would be such that these plans could be used to build a similar facility in the Middle West or any other part of the country.

Mr. FLOBERG. I suppose if you ever wanted to duplicate it, and if you ever had a body of scientific talents that was capable of utilizing it to advantage, it could, with probably relatively minor modifica-

tions, be duplicated. I would actually doubt you would ever want to duplicate this facility, however.

Representative PRICE. Mr. Toll.

Mr. TOLL. Mr. Floberg, on the breakdown of your construction projects data sheet it is indicated that the accelerator will cost around $23 million, equipment $9.6 million, and it is also indicated there is a 15-percent contingency in there of $13.4 million.

In many of your other items the construction costs are for buildings, improvements to land, utilities, and the tunnel. I wonder if the Commission needs the 25-percent flexibility on this project since a large percentage of your construction costs are on more or less conventional items, and you have a 15-percent contingency included in there also.

Mr. FLOBERG. Yes. These figures have been made up in the conventional fashion, Mr. Toll. The 25 percent overrun allowance that we have asked for is a conventional allowance for other projects where similar breakdowns of figures are made. We think, on the basis of our present judgment, that the $105 million, which is broken down in the fashion which you described, should cover the cost of the project.

The request for the overrun allowance is in case we turn out to be wrong on any one of these basic facilities, principally the technical one.

Mr. TOLL. You already have a $13.4 million contingency here. In effect you are asking for another $26 million contingency, and also an escalation provision of $9,340,000. The estimated cost of your accelerator is $23 million and some, and in effect you are asking the Congress to give you an awful lot of flexibility here as to the estimated cost of the accelerator, which could double or more without the Congress having another look at this.

Mr. FLOBERG. Your arithmetic is obviously correct. I don't really understand how there is any difference between this and any other technical project that we come in with to you.

Mr. TOLL. A large fraction of the cost here pertains to conventional facilities where your costs, as Senator Bennett indicated, could be fairly accurately estimated.

Mr. FLOBERG. That is a true statement, that a good many of these conventional facilities can be pinned down quite well. If you are saying to me, by your line of questioning, that you think that the 25 percent overrun allowance is too big an overrun allowance and it should be some other overrun allowance, my only answer to you is that 25 percent is one of the conventional figures that is used by this committee. If the committee in its wisdom decides that a different figure is appropriate, that is its privilege.

Mr. TOLL. I don't believe that is on all projects. Sometimes it is 10 and sometimes it is 15.

Mr. FLOBERG. It is one of the figures. As I say, if the committee decides that it would prefer to use another figure, I don't see how we are in a position to challenge the judgment of the committee.

Mr. RAMEY. The 25 percent is on the technical facilities and it doesn't make a distinction in the conventional facilities mixed with it. For example, if you are building the community facilities at Los Alamos or something like that, that is where they apply the 10 percent limitation.

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important to the defense system of the Nation and which is also the power source for electron linear accelerators. Dr. Ginzton is prepared to describe the details of the accelerator and the plans for its construction to you later in these hearings. He will also tell you of the plans for using this accelerator including national participation by scientists from universities and other laboratories.

Before turning to these gentlemen for such detailed presentations, I would like to review briefly some of the background of accelerators and the role they have played in understanding the nucleus of the atom. Also, I would like to give you our thinking on existing and future program levels. We will attempt to build on this background some of the reasons why it is considered necessary that this country proceed now with the construction of the proposed electron linear accelerator at Stanford University.

It is estimated by the SAC–GAC Panel that by fiscal year 1963 the cost of the high energy physics program, considering only accelerators presently existing or under construction, would be about $75 to $80 million per year. (See app. 2, p. 527, for SAC–GAC panel report.)

Representative BATES. Is that an operating cost?

Dr. WILLIAMS. That is the operating cost of those accelerators, plus the costs for their improvements required by the development of the technology.

Representative BATES. It includes improvements?

Dr. WILLIAMS. It would include improvements.

The SAC–GAC Panel further stated that it was their best judgment that by fiscal year 1963 the annual cost of high energy physics, including the expansion, would be about $135 million. The annual cost of the Stanford machine will be about $15 million or slightly more than 10 percent of the total program.

The ultimate goal of the Commission's program in nuclear physics is a complete understanding of the structure and behavior of the nucleus. The importance of this knowledge is evident to you from the applications of nuclear energy which have come from our present limited knowledge, which has been acquired through great effort during the short span of the past quarter century. This limited knowledge has established that the enormous forces which bind the parts of the nucleus together provide the reservoir of energy from which the world's future power demands must be drawn. It has shown us how to make the first steps in exploiting this source of energy. To understand in detail the forces within the nucleus is our goal.

Particle accelerators have been the essential tools employed by scientists to take the nucleus apart in order to study its structure. Higher and higher energy accelerators have been required to study in more and more detail this structure which is so firmly bound together by enormously strong internal forces. Both Dr. Haworth and I will return to this point later on during these hearings.

Looking back over the past 25 years we can see that some nuclear phenomena such as the production of radioactive isotopes, neutrons, and fusion reactions were first discovered by the use of nuclear particles which are emitted by naturally radioactive materials. This committee is very familiar with some of the earlier and simpler types of particle accelerators, such as cyclotrons and Van de Graaff genera-

On the location of the accelerator, was any consideration given to locating this at Livermore? That is within commuting range of the Stanford people, and it is more of a national laboratory site, with a lot of qualified technical people.

Mr. FLOBERG. That is correct. Consideration was specifically given to Livermore for the reasons you mentioned. Livermore is geologically unsuited to the construction of this large machine. The alluvial soil at Livermore would not stand the weight of this construction.

Representative PRICE. Is that the reason for the preference for the Stanford site over the Livermore site?

Mr. FLOBERG. That is the reason for eliminating Livermore from consideration.

Representative PRICE. That eliminated Livermore?

Mr. FLOBERG. Yes, sir.

Representative PRICE. That is the reason why you eliminated Livermore as a site?

Mr. FLOBERG. Yes, sir.

Representative PRICE. The next witness will be Dr. John H. Williams, Director of the Division of Research of the Atomic Energy Commission.

STATEMENT OF DR. JOHN H. WILLIAMS, DIRECTOR, DIVISION OF RESEARCH

Dr. WILLIAMS. Mr. Chairman, my name is John Williams. It is a privilege to present to you and to members of this committee the detailed information which supports the Commission's statements on the importance of this giant electron accelerator as a necessary addition to the Nation's high energy research facilities. It is our immediate purpose to provide you with the technical and scientific reasons underlying our request for authorization of this facility. Because of the complexity of this installation, two witnesses will be with us today who have special competence to amplify the statement of the Commission.

The first of these two experts is Dr. Leland J. Haworth, who is well known to you as the Director of the Commission's Brookhaven National Laboratory. He was also a member of the Science Advisory Committee-General Advisory Committee Joint Panel and was Chairman of the National Science Foundation Panel on High Energy Accelerators. These panels of experts helped to develop the recommendations which formed the basis of our national planning in the important forefront area of high energy accelerators and high energy physics. He is prepared to present to you later today a formal statement of the scientific reasons underlying the selection of the 10 to 15 billion electron volt electron linear accelerator as a tool required to advance our understanding of nature in the field of high energy physics. He will also assist in answering, as an internationally recognized authority in this field, your questions on this subject.

Furthermore, I know that this committee will find it both necessary and informative to hear the technical details of the proposed project. For this reason, Prof. Edward Ginzton of Stanford University is here to tell you about the proposed machine. Dr. Ginzton, who is in overall charge of the project, is widely recognized as one of the principal developers of the klystron, the radio-frequency power tube so

HIGH ENERGY ACCELERATORS IN OPERATION

DOMESTIC

MACHINE	ENERGY	PARTICLES	LOCATION
Synchrotron	1.4 Bev	Electron	Calif. Inst. of Tech.
A. G. Synchrotron	1.5 Bev	Electron	Cornell University
Synchrotron	3.0 Bev	Proton	Brookhaven
Synchrotron	6.2 Bev	Proton	Univ. of California

FOREIGN

Synchrotron	1.0 Bev	Proton	Univ. of Birmingham, U.K.
Synchrotron	1.2 Bev	Electron	Rome, Italy
Synchrotron	3 Bev	Proton	Saclay, France
Synchrotron	10 Bev	Proton	Dubna, USSR

Beginning operational dates on Bev. accelerators in operation, for inclusion in the Stanford accelerator hearings, July 14, 1959

Machine	*Year*
Synchrotron, California Institute of Technology	1956
AG synchrotron, Cornell University	1956
Synchrotron:	
Brookhaven	1952
University of California	1954
University of Birmingham, United Kingdom	1953
Rome, Italy	1959
Saclay, France	1958
Dubna, U.S.S.R.	1957

Representative VAN ZANDT. Could you also furnish information as to the many improvements being made?

Dr. WILLIAMS. Yes, sir.

(The material referred to follows:)

Improvements made in Bev. accelerators presently operating—for inclusion in the Stanford accelerator hearings, July 14, 1959

Accelerator	Initial operation		Present operation	
	Energy (Bev.)	Current (micro-amperes)	Energy (Bev.)	Current (micro-amperes)
Synchrotron, California Institute of Technology	0.5	10^{-2}	1.4	10^{-2}
AG synchrotron, Cornell University	1.2	10^{-2}	1.5	10^{-2}
Synchrotron, Brookhaven	2	10^{-4}	3	10^{-3}
Synchrotron, University of California	4	10^{-4}	6	10^{-3}

tors. These tools are still widely used in the physical research program of the Commission to provide the more accurate information needed to refine our knowledge of such processes as fusion, fission, and radioactive decay.

Early clues to the even more complicated structure of the nucleus came from the study of rare events produced by cosmic-ray particles with many billions of volts of energy. Unfortunately, the paucity of such events and the complexity of the cosmic rays reaching the earth makes impossible the understanding of truly high-energy phenomena, but served only to portray to us their mystery. Cosmic-ray observations did, however, show that it would be necessary to develop more powerful particle accelerators in order to provide protons and electrons with billions of electron volts of energy. The invention of such tools began in the late 1940's and soon resulted in several accelerators with energies between one-half and 1 Bev.

Last year the Subcommittee on Research and Development of the Joint Committee on Atomic Energy was told of many of the various types of accelerators in the energy region up to 1 Bev. which are being supported by the Commission for studies of nuclear physics.

For the purposes of the present hearings, we would like to confine our attention to those accelerators which provide electron and proton beams with energies in excess of 1 billion electron volts. This arbitrary cutoff point is chosen to encompass only those machines which have the power of producing detectable numbers of K-mesons. K-mesons are the lightest of the so-called "strange particles," which we believe play an important role in the nucleus. Dr. Haworth will, following my statement, discuss the nature of these "strange particles" whose important properties are so little understood. The investigation of the properties of strange particles is presently occupying the talents of a major fraction of high-energy physicists. Let us, for the present, confine our attention to such high-energy machines and delay discussing their uses.

In the United States today we have four accelerators which satisfy the criterion of being able to produce energies above 1 Bev. On the first chart (see p. 33) are these four U.S. accelerators and the four foreign accelerators presently operating in the energy region above 1 Bev. They are the electron cyclotron at California Institute of Technology which has 1.4 Bev.

Representative PRICE. While you are doing, would you mind giving us the dates when each of them came in?

Dr. WILLIAMS. I don't have that with me. I will make an approximate guess which I will correct later.

(Data furnished are on p. 33.)

Dr. WILLIAMS. The CIT cychrotron is operating at 1.4. When it first came in it was 1 Bev. It came in approximately 5 years ago. The alternating gradiant cychrotron at Cornell University now accelerates electrons to 1.5 Bev. These are similar machines. They differ only in their current characteristics; both came in at about the same time.

These are electron machines as distinguished from the proton machines. The two proton machines, the 3.0 Bev. at Brookhaven was the first billion electron volt accelerator in the world. Dr. Haworth is here and is in charge of that. Many of you have seen it. The University of California Bevatron, which is really a cychrotron, accelerates protons to 6.2 Bev. and is our highest energy machine. With this we are making very many important discoveries. For example, the antiproton was first discovered there and some of the strange particles which Dr. Haworth will tell you about.

On the bottom of the chart is the foreign situation. There are four similar machines. The one at Rome, Italy, has just come in this year. There is one electron accelerator presently operating and three proton accelerators. The Birmingham one is just at the low limit of 1 Bev. The one Russian machine at 10 Bev. is of higher energy than our 6.2 although it is not nearly as effective machine because of the lower current. So the situation is about an equal number of domestic and foreign machines.

Representative VAN ZANDT. Doctor, let me ask you a question about the domestic U.S. machines. Is it possible to expand their energy production or have they reached the limit?

Dr. WILLIAMS. The circular machine cannot be expanded because the energy which is produced is built in by their physical dimension. The only way to do it is to raise the magnetic field and they are presently operating at nearly that limit. These electron machines have been able to increase their energies slightly by providing more power. These are really built with this energy and can be extended only a little bit if at all.

Representative VAN ZANDT. Then the Brookhaven and University of California machines are producing energy to the extent of their capacity?

Dr. WILLIAMS. That is right. The experiments that can be done with them can be improved.

We cannot raise the energy. In the next chart (see p. 35), I have listed the high energy accelerators under construction. We have the four machines presently under construction in this country, one of which is an electron accelerator being built at Cambridge, Mass., a joint effort of MIT and Harvard which will produce electrons in a circular machine at 6 Bev. and consequently cannot be expanded for the same reasons I just stated.

The three proton machines: The cyclotron at Princeton is comparable to the cosmotron at Brookhaven but is a higher current machine but to a higher repetition rate, the two machines presently under construction, the one at Argonne just now beginning, will produce a large current of 12.5 billion electron volt protons and the one which will be coming in shortly at Brookhaven, the strong focusing synchrotron which will produce protons of energy of 25 to 30 Bev. This is the crop that will come into being within the next few years.

HIGH ENERGY ACCELERATORS UNDER CONSTRUCTION

DOMESTIC

MACHINE	ENERGY	PARTICLES	LOCATION
Synchrotron	3 Bev	Proton	Princeton University
A. G. Synchrotron	6 Bev	Electron	Cambridge, Mass.
Z. G. Synchrotron	12.5 Bev	Proton	Argonne
A. G. Synchrotron	25-30 Bev	Proton	Brookhaven

FOREIGN

Linear Accelerator	1 Bev	Electron	Saclay, France
Synchrotron	1 Bev	Proton	Delft, Netherlands
A. G. Synchrotron	1.2 Bev	Electron	Lund, Sweden
A. G. Synchrotron	1.3 Bev	Electron	Tokyo, Japan
Synchrotron	7 Bev	Proton	Harwell, U.K.
A. G. Synchrotron	7 Bev	Proton	Moscow, USSR
Synchrotron	10.6 Bev	Proton	Canberra, Australia
A. G. Synchrotron	28 Bev	Proton	CERN
(A. G. Synchrotron	50 Bev	Proton	Moscow, USSR)

Representative VAN ZANDT. Could you in a few words give us some idea when these machines will become operational?

Dr. WILLIAMS. Yes; I would be happy to. The (AG) synchrotron at Brookhaven will come in of the order of 12 to 19 months. The proton synchrotron at Argonne has just broken ground and they have an optimistic schedule of 3 to 4 years on it. The first two smaller machines at Princeton and Cambridge were originally thought might be coming in approximately 1 year from now but there seem to be delays of the order of 6 months or so. So we are essentially 18 months away on these. It is hard to say when they will really operate. They will try to bring them in at that time. The (AG) synchrotron at Brookhaven will probably be the first of these that come in.

Representative WESTLAND. Apparently this (AG) synchrotron at Cambridge is circular?

Dr. WILLIAMS. Yes, sir.

Representative WESTLAND. Is the AEC or the Federal Government participating in that project?

Dr. WILLIAMS. It is being done under a contract with the Atomic Energy Commission. All of these machines are under contract with the Atomic Energy Commission.

The foreign situation now, one sees in this case nine machines presently under construction that we know about. The question of brackets here on the 50 Bev. machine which we believe to be presently under construction in Russia indicates some paucity of information about its prospects. We do not have a complete set of information on it. The others we have a great deal of information on. You see they are distributed throughout the world all the way from Australia to Japan, Moscow, and so on. I wanted to show you this list to indicate

that the rest of the world feels that this is an important area of research worthy of their support.

Representative PRICE. Doctor, you may be interested in the story about how the Russians look upon the capacity of these accelerators. One country gets one of 6 billion and the next one gets 10 billion. Then the other jumps a couple of more billion. The Dubna Laboratory asked our group when we were there 2 years ago how we got the money to build our accelerators. We told him the legislative process of getting money on our program. He said, "that is not the way I understand." He said, "I understand you get it by saying the Russians have a 10 billion electron volt synchrotron and we need a 20 billion electron synchrotron and that is how you get your money." I said, "there may be something to it." I said, "How do you get your money?" He said, "The same way."

Dr. WILLIAMS. That is certainly a very true story. On the other hand, I fall back on the recommendations of this panel of experts who saw no reason to recommend competition with this 50 Bev. proton accelerator.

Representative VAN ZANDT. Doctor, have you got an operational date on that 50 Bev. machine?

Dr. WILLIAMS. We have some guesses on it. It has been estimated at various time at 1960, 1961, or 1962. We do not have enough information to confirm or deny that.

Representative VAN ZANDT. Going back to the domestic effort in the United States, is it not true we augment the effort with machines of lesser energy, which are distributed throughout the country among educational institutions?

Dr. WILLIAMS. Definitely, Congressman Van Zandt. The low energy machines distributed throughout the universities are doing a great deal of very valuable work in the area of nuclear physics and providing very valuable data.

The high energy machines are our forefront machines, exploring at the very tip of science. Both kinds of machines are working in nuclear physics in various areas where different phenomena occur.

Representative VAN ZANDT. In your statement, I think you said the overall cost of this effort amounts to about $135 million.

Dr. WILLIAMS. That is right. By fiscal year 1963, using the assumptions contained in SAC–GAC panel (see p. 537), the cost of high energy physics should reach a level of $135 million.

Representative VAN ZANDT. Would it be proper to say that, from the standpoint of educational institutions and the contribution they make in this field, non-Government money is being spent?

Dr. WILLIAMS. Not entirely non-Government money. It is partial Government money and partial local university and institutional money.

Representative VAN ZANDT. It is mostly Government money?

Dr. WILLIAMS. The division between those two in that particular area of support, what we call intermediate and low energy nuclear physics—I could supply this better for the record—is a 70–30 basis, 70 from the Government and 30 from the institutions.

Representative VAN ZANDT. That would be in addition to the $135 million?

Dr. WILLIAMS. Yes. It is a different category. The $135 million is for high energy physics.

Representative PRICE. Dr. Williams, would you hazard an answer to this question? Looking at your chart I don't see a linear accelerator under construction by the Russians. If the project that we are considering today is so technically feasible and valuable, why aren't the Russians building one?

Dr. WILLIAMS. I am very happy to answer that question because it gives me an opportunity to say that we are indeed fortunate in this country to have a lead in the development of the linear electron accelerator largely based on the development of the klystron and its application to electron linear accelerators which is completely unique in the world. We are fortunate to have those kinds of people at Stanford. This is the basic reason underlying our enthusiastic support of this proposal. It is clearly why we are in the lead.

Representative PRICE. I notice you have one listed as under construction in France, although much smaller. Nevertheless, it is a linear accelerator.

Dr. WILLIAMS. That is right.

Representative PRICE. Would that indicate that they are ahead of the Russians in this particular field?

Dr. WILLIAMS. Not necessarily the Russians. On the charts for the future, they have planned an electron linear accelerator in the 1 to 4 Bev. energy range at Kharkov. It is presumably to be similar to the Stanford one now under discussion. It is an extension of an existing one by a factor of about 40 over what they presently have, I am told, whereas we are proposing an extension of 40 over the existing Stanford one. This about catches them up to where we presently are. If I may turn to the high energy accelerators now (below) un-

HIGH ENERGY ACCELERATORS DESIGNED

DOMESTIC

MACHINE	ENERGY	PARTICLES	LOCATION
Linear Accelerator	10-15 Bev	Electron	Stanford University

FOREIGN

Synchrotron	1 Bev	Electron	Moscow, USSR
Linear Accelerator	1-4 Bev	Electron	Kharkov, USSR
(A. G. Synchrotron	4 Bev	Electron	USSR)
A. G. Synchrotron	7.5 Bev	Electron	Hamburg, Germany
(A. G. Synchrotron	50 Bev	Proton	USSR)

der design, we are proposing to this committee for authorization of construction this one item, the Stanford 10 to 15 Bev. electron linear accelerator. We know of the present design situation for the five foreign machines shown in the chart. In fact the Hamburg electron synchrotron is getting under construction just now. It is passing the design stage and should be transferred to the construction chart. You also see that this (AG) synchrotron at 50 Bev. is also listed in this design category chart, too, because of our uncertainty whether it is under construction or under design.

Representative BATES. Doctor, you gave a general conclusion why you develop your proton accelerators at 25 to 30 Bev. You say that is adequate to your purposes?

Dr. WILLIAMS. We want very much to see what kind of physics comes out of them before we make any proposal to beat the Russians on any energy scale. We want to use the machine and see what the future demands are and not go into an energy cold war.

Representative VAN ZANDT. Doctor, have we been successful in any way to arrange for the exchange of information in this higher energy field with the Soviets.

Dr. WILLIAMS. We had a meeting 2 years ago this month at Geneva which I attended, and there is a meeting arranged for September 14 to 19 in Geneva again. From then on it is planned to rotate between this country, Geneva, and Russia. This is certainly an exchange of information on a 2-year basis. We have a great deal of exchange on a very current basis with the Western world. There is a formal exchange every 2 years with the Russians.

Representative VAN ZANDT. Is it proper to assume that from the machines being built in other countries of the free world, the research findings will be available to the United States?

Dr. WILLIAMS. Definitely. They are currently available by visits, communication, and formal publications. There is no problem on the interchange of information.

Representative VAN ZANDT. Doctor, what plans have been developed to implement the construction of other accelerators recommended by the President's Special Advisory Panel?

Dr. WILLIAMS. The President's Advisory Science Panel did not recommend the construction of any other accelerators. They pointed out a need for a high intensity proton accelerator—a very high intensity proton accelerator—of energy greater than 8 Bev. There are no existing proposals before any Government agency for such a machine. We are presently supporting in the Commission a design group at the Midwestern University Research Association at Madison, Wis., which may propose such a machine. We are also supporting a group at Oak Ridge National Laboratory.

Representative PRICE. With respect to the country's planned future cost, what does the Stanford accelerator represent?

Dr. WILLIAMS. If we make the assumptions that were made by the SAC–GAC Panel that the cost of high-energy physics in fiscal year 1963 would be $135 million a year and the Stanford one will operate at $15 million or a little more per year, this is something of the order of 10 to 15 percent of the national effort at Stanford.

Representative PRICE. Making that assumption, we note that the $135 million annual rate would be reached by the authorization of one

additional machine comparable to the Stanford machine prior to about 1963, we also note the special panel report also recommends increase in support of present accelerators and the construction of additional machines not necessarily unique to expand basic university facilities in this field. What are the plans for implementing these recommended fields within this $135 million rate?

Dr. WILLIAMS. The Commission weighs proposals from individual competent groups for support. At the present time, with the oncoming of these new machines presently under construction and their instrumentation, our major plan is to support what we presently have under construction and what we have under operation as our first priority. This will cause the growth of the order of $80 million a year. With the Stanford one added to that, then you ask what comes next. If a high-intensity proton accelerator proposal comes to us and it seems appropriate in our planning we would bring it to you. That would then increase the cost, if it were deemed advisable at that time. On top of that we anticipate receiving proposals of a less unique and less forefront character from major institutions or a group of institutions throughout the country. These we have not yet received and analyzed to the state that we want to present them to you at this time.

Representative BATES. Doctor, will you explain to a layman why you adopt a linear accelerator rather than expanding the radius of a circular accelerator?

Dr. WILLIAMS. I should be very happy to. In a circular accelerator the electrons must change the direction of their path. In technical language that means it must be continuously accelerated to the center. It is pulled in like a string on a Yo-yo. The amount of energy that you have to spend in pulling it toward the center grows rapidly with the total energy of the circulated particle. Indeed it goes as the fourth power of the energy, the power required to do this useless process of pulling to the center. So with any modest limit on the amount of radio frequency power that you want to waste, the maximum energy that we foresee as being technically feasible is of the order of 7 or 8 Bev. for a circular machine. Otherwise, the amount of power grows so rapidly that it is the fourth power of total energy. This is a practical upper limit of what you can get.

Representative VAN ZANDT. Doctor, I notice in your original planning for the Stanford machine you estimate this cost at about $80 million?

Dr. WILLIAMS. That was the Stanford estimate.

Representative VAN ZANDT. I understand it was $78 million. Then the Brobeck Associates came through with a cost figure of $115 million?

Dr. WILLIAMS. That is right.

Representative VAN ZANDT. Then you arrive at a current cost estimate of $105 million. Can you go into a little detail as to why the variance there between the two figures?

Dr. WILLIAMS. Yes. I have in my hand here—chart No. 4—a three-column table showing this list which we will be very happy to pro-

CHART 4

Cost comparisons between Stanford, Brobeck, and AEC estimates

Items	Stanford	Brobeck	AEC
(a) Engineering, design, and inspection	$19,171	$17,660	$7,600
(b) Land			
(c) Construction costs:			
(1) Improvements to land	1,799	783	1,956
(2) Buildings	8,610	6,534	10,500
(3) Utilities	4,862	11,858	12,042
(4) Tunnels	10,420	15,831	16,764
(5) Accelerator	28,292	27,987	23,789
(6) Equipment	6,417	10,785	9,600
(d) Escalation	Prorated	13,156	9,349
(e) Contingency		11,402	13,400
Total	79,571	115,996	105,000

vide for the record. In fact I think in order to help my discussion with you I would like to give you copies of this table so that we can refer to it in my discussion. This table has been drawn up in terms of the categories on the left-hand side which are appropriate to the way in which we present the data sheets to the Bureau of the Budget and your committee. So they have to be translated backward to the left in terms of the Brobeck analysis and the Stanford original proposal. (a) Engineering design and inspection, Stanford, Brobeck, and AEC, you see Stanford and Brobeck are not far apart on this. AEC is low. The answer to this is simply that the $18 million of research and development which we are asking aside from $105 million of construction is the way the Atomic Energy Commission runs its business of separating out research and development from construction. So that the difference there is accounted for.

As we go through this column, then, there are no really major differences that occur except in the matter under c–3, utilities. You will see that the Stanford original estimate was very much underestimated, probably from a lack of detailed engineering studies. The further principal differences occur under equipment in which Brobeck incorporated a lot in the $10 million figure as compared to the Stanford figure who delayed in their planning the provision of such equipment.

However, the principal difference lies in d and e where Stanford had prorated an escalation based on 2 or 3 years ago and had specifically put in no contingency figures. So we feel that if you analyse this table in detail that there is essentially no major difference, except the following: That the machine we are presently proposing to be built consists of 240 klystron power tubes rather than the 480 on which the Brobeck analysis was made.

Representative PRICE. While you are on the physical matter, I would like to propound a question to the Chairman of the Commission, and I assure him to begin with that this does not reflect my personal position, but this is for the record. I have observed that the best chance to get legislation passed dealing with finances in either the House or the other body is to be able to show that you have reduced the request. Why should the full $105 million be authorized at this time? Why not the initial authorization, being for the purpose of

taking care of design and engineering studies and associated research and development?

Mr. FLOBERG. If I could answer your question, Mr. Price, we have talked this very question over at great length. Our answer to that question is that we feel that the scientific community that is going to develop this project must be given the certainty of having a real project on their hands in order to keep them attracted to the work in question. It is our feeling, based on the best investigation that we can make, that we have a very challenging project here. It is going to tax the imagination and scientific capability of one of the most uniquely qualified groups of people in the world. There are plenty of other places that they could put their interest and energies if they chose to do so. The best way to guarantee the maximum performance and a complete followup on a first-class project here is to give them the assurance of a final completed project to which to devote their talents.

Mr. MCCONE. Supplementing that statement, Mr. Chairman, I would like to point out that this group has been working now for several years, as both Mr. Floberg and Dr. Williams have said, on the development, and they have built a small section of this accelerator which is operating at 730 million, and will go to a billion electron volts. We feel that the time has come, and the GAC–SAC Committees have felt that the time has come to reduce this down to a specific project. Further postponement of considering the project per se and merely continuing the project in its development stages would have the effect of discouraging rather than encouraging the project and having it go forward with the vitality that is required.

Representative PRICE. Has the design, engineering, research, and development reached the point where you are practically ready for construction?

Mr. MCCONE. Dr. Williams could best answer that.

Dr. WILLIAMS. We could, I am told, and I believe, simply duplicate 40 of the existing prototype machines. This would not be the proper way to build a machine in which we want complete 24-hour-a-day automatic operation. So there will be a necessity to make further developments on the components to produce reliability. In addition, the matter has to yet go through the detailed design stage. So it is more than a conceptual design that exists. An actual prototype design exists, but it is not one that you want to apply in 40 connected parts. You want to improve that. That is where a lot of the research and development planning and money will be required.

Mr. RAMEY. You do not actually have what is called a title 1 design?

Dr. WILLIAMS. Not a complete title 1 design, no.

Mr. RAMEY. I notice your data sheet shows for fiscal 1960, obligations of $3,700,000, including architect-engineer studies on buildings, and actual initiation of construction on the administration building. So you have to have construction money for that.

Dr. WILLIAMS. That is right. The construction money which is requested there is largely for the construction of the facilities required to get this show on the road.

Representative VAN ZANDT. Dr. Williams, your request for the authorization of $105 million, I take it, is based on this statement which I lift from your statement. I quote:

I am informed that in order to build a higher energy accelerator it is necessary only to reproduce a longer version of the machine of the type already in operation.

Is that correct?

Dr. WILLIAMS. That is what is in Mr. Floberg's statement. I agree with it completely. You could do it that way. However, I think it would be improper to duplicate a machine which presently exists 40 times when you know very well with this effort one can build better, more reliable and more powerful and useful machinery.

Representative VAN ZANDT. Have you a lot of the hardware already available?

Dr. WILLIAMS. The hardware for the one-fortieth scale prototype one exists. This machine has been operating for years. There is no hardware procured for the big one as yet. We have no authority to do so.

Representative VAN ZANDT. It is going to take 6 years to complete this project.

Dr. WILLIAMS. That is the planned construction schedule.

Representative PRICE. I think this is the way to expedite the project. I personally would be inclined to approve this plan. As a matter of fact, I thought that way in many of the reactor programs of the past, but the Commission felt a little differently in those programs.

Representative VAN ZANDT. May I ask Chairman McCone, What is the program of actually funding this project?

Mr. MCCONE. We will fund it annually over the period of the construction in accordance with the schedule that we have here. The first year is modest. These funds can be provided. Fiscal 1960 calls for $3.7 million; 1961 for $12 million; fiscal 1962, $50 million; fiscal 1963, $22 million; fiscal 1964, $15 million; fiscal 1965, $2.3 million. Those are the obligation authorities for the years involved.

Representative VAN ZANDT. In other words, the big expenditures will not take place for about 3 years.

Mr. MCCONE. No. The expenditures would lag even behind those figures. They would run $2 million fiscal 1960 and $7 million in 1961, for a total of $9 million in those 2 years, against obligation authority of $15.7 million in those 2 years. In 1962, there would be an expenditure of $30 million against an obligation authority of $50 million. Then in the subsequent years the obligation authority drops off and the expenditures rise and then drop off more slowly.

Representative VAN ZANDT. To keep this project on schedule construction must start in the fiscal year of 1960.

Mr. MCCONE. That is correct.

Representative BATES. Mr. McCone, I understand that the one at Cambridge will be completed next year.

Mr. MCCONE. In about 18 months.

Representative BATES. Will we have advanced so far on this at that particular time that we could not take advantage of the information we will secure by that time from the Cambridge accelerator?

Mr. MCCONE. I will ask Dr. Williams to reply to that.

Representative BATES. Would it be worth while to slow this down initially until we get this information?

Dr. WILLIAMS. The Cambridge machine will operate at 6 Bev. We know very well in this energy region what kind of problems it can do and they are very important problems. We have every reason to continue with it. On the other hand, we know of very important problems that are required to be done at a higher energy and also and more importantly the kind of problems which can be solved with this machine due to its linear attributes, its external beam which proceeds out into space, the well defined linear character of the columnated beam which will allow us to make physical examinations that are quite unique. It is true that the physics information that we get out of the Cambridge machine will guide us in the kind of nature of experiments to be done, but it will in no way replace the need and requirement for the linear machine.

Representative BATES. You don't feel that you will have advanced so far on this new one that it will in any way effect any changes that you might want to make because you don't expect such changes will be required?

Dr. WILLIAMS. These will not be technological changes that would influence the detailed design of the linear machine; the connections are rather tenuous between the design of a circular and linear machine which are so different.

Representative VAN ZANDT. Chairman McCone, will this machine be located on Government property or Stanford University property?

Mr. MCCONE. Stanford University property.

Representative VAN ZANDT. What is the nature of the lease?

Mr. MCCONE. It will be a long-term lease at no cost to the Government.

Representative PRICE. Perhaps it might be advisable to take Mr. Younger now, and we will continue with the Commission's testimony this afternoon.

Congressman Younger, will you come around.

STATEMENT OF HON. J. ARTHUR YOUNGER, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF CALIFORNIA

Representative YOUNGER. Thank you very much, Mr. Chairman, for the privilege of being here. I just want to say a few kind words for California. I do not want to be in the position of even intimating that I have information or judgment as to whether or not this accelerator should be built, or whether it is necessary, considering the financial condition of the Government. All I wish to add are my thoughts on the question of the location. The question of its necessity, the question of the best and most economical location will, of course, have to be decided by your committee because you have facts which I do not have the possession of. But here in California is a location where you have ample space due to the fact that the campus has over 8,000 acres in it. That is, the campus and the adjoining property owned by Stanford University.

You also have coupled with that the scientists there in the university and in locating a factory or a project of any kind, it is always well to have it located where there is ample labor supply. Here you have the ample trained labor supply at Stanford.

Over and above that, you have a desire on the part of those people to see that this project is satisfactorily operated, and that is not always present. You have the good will of the surrounding territory for the installation of this project. That is not always present in a location of this kind, or in locating a project of this kind. For those reasons I just want to add my word in regard to the location.

Stanford adjoins our district. There is just the small creek that is the boundary between the Ninth District and the Tenth District in which Stanford is located.

That is all I have to say, Mr. Chairman, unless there are questions.

Representative PRICE. Thank you, Mr. Younger. We are glad to have your testimony. I am not aware of any controversy over the site selection.

Representative YOUNGER. There has been quite a bit of publicity out in California as to a controversy by the State of Washington offering a free tunnel up in Congressman Westland's district. That has been publicized quite a bit out there as one of the possible sites.

Representative WESTLAND. Mr. Chairman, I don't care to reveal my hand completely at his time, but we do have a 2-mile-long tunnel in the Cascades there that you will hear something about a little later. I might say it would save the Federal Government a rather substantial amount of money if it could be used.

Representative VAN ZANDT. If the gentlemen from California and Washington are not interested in this project, we have a lot of abandoned coal mines in Pennsylvania suitable for it and we would welcome the project.

Representative YOUNGER. I assure you, Mr. Chairman, I did not have any idea of creating any controversy here.

Representative PRICE. Thank you very much.

Representative YOUNGER. Thank you.

Representative PRICE. The committee will stand in recess until 1:30 this afternoon.

(Thereupon at 11:45 a.m., a recess was taken until 1:30 p.m. the same day.)

AFTERNOON SESSION

Representative PRICE. The committee will be in order.

This afternoon we resume public hearings on the proposed Stanford linear accelerator. At the start of the afternoon session, the Chair will recognize the gentleman from Washington, Mr. Westland, for a statement.

STATEMENT OF HON. JACK WESTLAND, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF WASHINGTON

Representative WESTLAND. Mr. Chairman, inasmuch as Congressman Younger brought this subject up earlier this morning, I thought it would be of interest to the committee and perhaps to the Commission, although I believe they have heard something of this, and I believe Dr. Williams has heard something of this tunnel, too, I might start out by saying I have a tunnel already constructed. A tunnel which is 2.6 miles long, which is as straight as an arrow or anything you want to call straight. It has 2 feet of concrete around it, some of it steel reinforced. It is 16 feet wide and it is 20½

feet tall. It is through granite. You can drive up through it in an automobile. This tunnel is presently available. As a matter of fact, the gentleman who owns this tunnel, or at least has an option on this tunnel, is here in the audience. I don't know whether or not this particular tunnel will satisfy the requirements of this linear accelerator, but I know that at least in the dimensions which have been mentioned, the tunnel is about the same. It would seem to me that the Atomic Energy Commission might very well take a look at this place. It is up in the mountains. It is a tunnel where trains went through. Maybe it doesn't have quite the climate that Stanford has at Palo Alto, but it is a pretty nice place, too. It is within half a mile of U.S. Highway 2, which is a fairly important highway. You can drive right up to it, as I said. I believe the estimated cost of this tunnel that you are figuring on building at Palo Alto is around $17 million, or something of that nature.

I think that this committee in deference to our taxpayers, which is certainly an overworked word but so are the taxpayers overworked, would at least have the Commission take a look at this place and give us a report.

One thought has occurred—the danger of earthquakes. I am told that this area where they are planning on building the present tunnel already has one fault in it. I would like the members of the committee who are here to just take a look at this sheet to show that I am not fooling, to show that it does exist. You can almost look from one end of it right straight through to the other. It seems to me if we are going to build a tunnel maybe we ought to take a look at one that is already in existence and maybe save $15 million or something of that nature.

Representative PRICE. Dr. Williams, would you care to comment?

Dr. WILLIAMS. Thank you, Mr. Chairman. I would be happy to comment on it. I think perhaps the best way to comment on this is to read from a letter which I addressed on July 2 to Senator Henry Jackson in response to his inquiry that we do investigate this situation. With your permission, I think it is the most brief answer I can give by reading the principal paragraph of this letter.

The Atomic Energy Commission, Division of Construction and Supply, has made an estimate of the comparative cost between the Stevens Pass site and the one proposed by Stanford University near its campus. They have found that locating the accelerator in the Cascade Tunnel would result in an increase of over $10 million in the total construction of this project. This increase in cost, in spite of the fact that a 2½-mile tunnel is already in existence, arises from the following:

1. The present tunnel would have to be widened from its present 16 feet to 24 feet in order to provide minimum space for the high power microwave electronics.

2. This tunnel must be pressure grouted to eliminate the inflow of water and provided with a concrete floor.

3. A parallel tunnel, 10 by 16 feet in cross section, is necessary to contain the accelerating tube itself.

4. The isolation of the site would result in increased labor costs.

5. Housing would have to be provided for the construction and scientific workers as the nearest town is Wenatchee, 65 miles away.

6. The heavy snowfall in this region would necessitate a heavier roof structure for the laboratory buildings and in general would impede construction.

In addition, it is estimated that the operating costs, once the construction is completed, would be at least $1½ million more for the Stevens Pass site than the Stanford location. In view of the increased construction and operating

cost, the Atomic Energy Commission feels that the Cascade Tunnel site should not be considered further. We appreciate very much your prompt action in calling this matter to our attention.

Representative WESTLAND. I must say that is rather an impressive document, Doctor, but I can certainly reply to some of the items. First of all the nearest town is not 65 miles away; it happens to be my hometown, which is about 45 miles away.

Dr. WILLIAMS. I am sorry we made a misstatement there.

Representative WESTLAND. There is adequate housing in many places in between those locations. There are many other comparatively small communities. I might also say that at one time the Manhattan project decided to build a place which was in eastern Washington and is now pretty well known. There was not anybody there, not as much as there is today in the near vicinity of this tunnel. Yet it is a pretty sizable operation now at Hanford. I would just ask this, Doctor: Does it cost more to expand a tunnel than it does to build a new one?

Dr. WILLIAMS. No, I would think not. I am not a construction engineer. However, the point that has not been made clear because I have not described the accelerator in detail is that we must have two parallel tunnels. The expansion from 16 to 24 feet cost would depend on the nature of the material. This is a granite structure, as I understand, and the cost of extracting that I am not in a position to give you detailed information on. Our construction and supply people have estimated the breakdown of the costs in these six points which I would be happy to provide for the record.

Representative WESTLAND. I would certainly like to have a copy of that letter.

Dr. WILLIAMS. I will give you a copy of the letter and the backup material.

(The letter referred to follows:)

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., July 2, 1959.

Hon. HENRY M. JACKSON,
U.S. Senate.

DEAR SENATOR JACKSON: This is in reply to your letter of June 4, 1959, addressed to the Chairman, concerning the possibility of utilizing the abandoned Great Northern Railway tunnel near Stevens Pass, Washington, as a site for the proposed Stanford 2-mile linear electron accelerator.

The Division of Construction and Supply of the Atomic Energy Commission has made an estimate of the comparative costs between the Stevens Pass site and the one proposed by Stanford University near its campus. They have found that locating the accelerator in the Cascade tunnel would result in an increase of over $10 million in the total construction costs of the project. This increase in cost, in spite of the fact that a 2½-mile tunnel is already in existence, arises from the following:

(1) The present tunnel would have to be widened from its present 16 feet to 24 feet in order to provide minimum space for the high power microwave electronics.

(2) This tunnel must be pressure grouted to eliminate the inflow of water and provided with a concrete floor.

(3) A parallel tunnel 10 by 16 feet in cross section is necessary to contain the accelerating tube itself.

(4) The isolation of the site would result in increased labor costs.

(5) Housing would have to be provided for the construction and scientific workers as the nearest town is Wenatchee, 65 miles away.

(6) The heavy snowfall in this region would necessitate a heavier roof structure for the laboratory buildings and in general would impede construction.

In addition, it is estimated that the operating costs, once the construction is completed, would be at least $1,500,000 more for the Stevens Pass site than the Stanford location.

In view of the increased construction and operating costs, the Atomic Energy Commission feels that the Cascade tunnel site should not be considered further.

We appreciate very much your prompt action in calling this matter to our attention.

Sincerely,

JOHN H. WILLIAMS,
Director, Division of Research.

BACKUP INFORMATION CONCERNING USE OF THE CASCADE TUNNEL AS AN ALTERNATE SITE FOR THE STANFORD ACCELERATOR FOR INCLUSION IN THE STANFORD ACCELERATOR HEARINGS, JULY 15, 1959 (FURNISHED BY AEC)

The railroad tunnel has a clear width of 16 feet, a height of 21.5 feet, and a length of 13,873 feet. It would be necessary to widen it to the same width as the Stanford equipment tunnel, 24 feet, and to drive a second tunnel for the accelerator, 10 feet by 16 feet, connecting the two tunnels with laterals every 250 feet. In addition to widening the existing tunnel, it would be necessary to undertake pressure grouting along some 10,000 feet of its length to cut down the inflow of water, to make repairs to the concrete lining, and to construct a concrete floor slab. Assuming purchase of the tunnel at Mr. Lomen's price of $1 million, the tunnel construction would cost $11,500,000 at the Cascade site as compared with the $18,900,000 included in our estimate for the Stanford site. However, this apparent saving of $7,400,000 is well below the substantial additional costs which would be incurred due to the isolation of the site, the mountainous nature of the country, and severe climatic conditions. These additional construction costs amount to $18,190,000, as described below.

One of the principal factors would be the increased cost of labor. Because of the isolation of the site, labor costs are estimated at about $6 per day extra or approximately $6,370,000 for the 8.5 million man-hours that would be required at the site.

This area has an average snowfall of approximately 30 feet, of which the usual accumulation amounts to 8 to 12 feet. Due to this snowfall, it would be necessary for extremely heavy roof construction to be used or some type of snow-melting device adopted. The extra cost is estimated at $470,000.

Housing for labor could not be found within reasonable commuting distances and construction of a labor camp, probably accommodations for trailers, would be necessary. It is estimated that 1,500 trailer spaces would be necessary at a total cost of $2,250,000.

Because of unfavorable conditions at the Cascade site, such as the shorter construction season, heavy snowfall, freezing weather, increased travel costs, etc., it is estimated construction costs would be increased by $1 million.

There are no communities of any size near this site, the closest cities being Wenatchee on the east and Everett on the west. It will probably be necessary to construct at least 500 houses for the operating staff at an estimated cost of $7,500,000.

At the Stanford site it is planned to obtain water and sewage services from municipal systems. A sewage disposal system will have to be constructed and a water supply developed at the Cascade site. These facilities are estimated at $600,000.

The additional costs described above total $18,190,000 which, when reduced by the estimated saving in tunnel construction costs, leaves $10,790,000 as the increase in the capital cost of this project over and above the cost if constructed at Stanford.

In addition to the above, the 10-foot tunnel for the accelerator itself must be absolutely level. Since the Cascade tunnel, which would house the kylstrons, etc., has a vertical slope the power losses occasioned by additional length of the connecting wave guide would be substantial.

An onsite inspection conducted by Commission engineers indicates that the terrain at both portals of the tunnel is very rugged and traversed by sizable streams.

No adequate land for buildings or experimental areas is available.

Representative WESTLAND. I may reply to some of this.

Representative PRICE. Doctor, may I ask this question:

Was your attention called to the availability of this tunnel by contact with Senator Jackson and Congressman Westland?

Dr. WILLIAMS. That is right. It was brought to our attention by Senator Jackson.

Representative PRICE. What study did you make as to the usefulness of the tunnel?

Dr. WILLIAMS. We were provided with the engineering drawings of the existing installation. We did not visit the site. We had an engineering drawing of the elevations and plans of this tunnel.

Representative PRICE. Your finding, on which you base your reply to the Congressman, is based only on this engineering drawing without any on-site inspection.

Dr. WILLIAMS. That is right. If I may, I would like to ask Mr. Radley of our Division of Construction and Supply to supplement any statements which I am making because I personally did not do this. It was under his direction.

Mr. RADLEY. We worked from drawings and available information provided by the holder of the option for the tunnel. We got some information on the climatic conditions from the Weather Bureau and used maps to try to find out what towns are in the vicinity. We could not find that there were towns of any size that they might be able to house our construction workers and the staff who will operate the accelerator. We expect that there will be a permanent staff of about a thousand which means that there would have to be quite a bit of housing for such a group.

Representative PRICE. Aside from the physical points that you raise and the difference in cost, are there any other requirements that this site might fail to meet. Would it meet your normal requirements otherwise?

Mr. RADLEY. We would have to develop a water supply at this particular site which I don't think would be particularly costly because there appears to be a stream flowing near there. I think power could be had in the vicinity. I think there are some transmission lines there. There seems to be some question as to the availability of sufficient level land at either end of the tunnel for the buildings which we would have to put up. Then there would be a great deal of difficulty with the heavy snowfall. It totals around 30 feet year, according to our information.

Representative PRICE. Senator Jackson, Congressman Westland raised the point of the availability of the tunnel in Washington State as a site for the proposed Stanford linear accelerator. That is the point we are discussing now.

Senator JACKSON. I am sorry that I was on the floor and could not be here when Congressman Westland asked the questions. I did receive the letter from the AEC on this, and as I understand the situation, they raise a question—I don't have the letter before me—about the problem in connection with high snowfall and the distance from the nearest town. Actually there are communities nearer than Wenatchee to the site of the tunnel. What I was interested in knowing was to what extent was it important that the people who are now at Stanford and pioneered the work in this field, which I understand goes back to World War II, be in the bay area, so to speak.

Mr. RADLEY. I think perhaps Dr. Williams should answer.

Dr. WILLIAMS. May I address myself to your question, Senator Jackson? It is certainly a matter of very great and primary importance that people be at that site and living there and make their homes there and exist as an integrated community. The reply that we addressed to you was confined only to the matter of the economics of construction. On that basis we demonstrated, I think, that there would not be a saving from the utilization of this narrower tunnel but would actually turn out to be a greater cost.

Senator JACKSON. Doctor, what about the possibility of damage in the California or Stanford area by earthquake?

As I understand it is in the area of the San Andreas fault.

Dr. WILLIAMS. In that case we have had five different independent groups of geologists look at this situation and assure us that within geologic history there has never been a fault at the actual location of this tunnel. There are certainly tremors and earthquakes but due to the design of this machine it is not sensitive to an earthquake that doesn't cause an actual fissure of the earth. The existing installations have operated there for years without the slightest damage from the earthquakes that do occur.

Senator JACKSON. Is there substantial reason to believe that it might be in an area where damage might occur?

Dr. WILLIAMS. This is a matter of geologic opinion. We have five teams of people who have said no. I would not make myself an expert over five teams of geologists. For more detail, Dr. Ginzton is here and can provide you with the names of those people.

Senator JACKSON. You don't have to be qualified in this field. You are relying on people who are qualified. What I want to ask you is this: Did any of the geologists dissent?

Dr. WILLIAMS. I will have to ask Dr. Ginzton to reply.

Dr. GINZTON. The answer is "No."

Senator JACKSON. I take it they are people who are considered very competent in their field.

Dr. GINZTON. Yes, sir. For example, Professor Richter of the California Institute of Technology was one of several experts consulted.

Senator JACKSON. I am not familiar with the experts in the field. I am taking your word for it. The point is that you got the best professional people. You say they are of unanimous opinion that the area is suitable despite the fact that it is not far from what is known as the San Andreas fault.

Dr. WILLIAMS. That is right, sir.

Senator JACKSON. It is quite an investment they are putting in.

Dr. WILLIAMS. We are very conscious of that.

Representative PRICE. Thank you.

Mr. Westland, do you have any further questions?

Representative WESTLAND. I might only add this, Mr. Chairman. There is no question about any geologic fault in this area where this particular tunnel is located. As the Senator from Washington has stated, there are other communities considerably nearer than Wenatchee. This is accessible at the present time by automobile off a principal highway, U.S. 2. It is already built. It would require additional building. It would seem to me that an estimate of cost

from merely a technical drawing would hardly be conclusive. The Atomic Energy Commission might very well make an onsite inspection of this property and see whether or not there is any justification for the possibility of its use.

Dr. WILLIAMS. I will take personal responsibility to see that competent engineering people do inspect this site.

Representative PRICE. May the Chair suggest that the Commission take a further onsite look at this area and then report back to us your findings. (See p. 47 for backup information furnished by AEC.)

Mr. FLOBERG. Yes. We have no hesitation at looking at Congressman Westland's tunnel. We will certainly do that.

Representative PRICE. Dr. Williams, before we proceed with the Commission testimony we will call our colleague from the House, Congressman Gubser.

STATEMENT OF HON. CHARLES S. GUBSER, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF CALIFORNIA

Representative GUBSER. Thank you, Mr. Chairman, and members of the committee.

I would like to express my thanks for the opportunity of appearing before you in favor of bills to authorize the construction of a linear electron accelerator at Stanford University. As you know, I have introduced H.R. 7468 for this purpose.

Since technical testimony will be presented by experts, I shall confine my remarks to the facilities available at Stanford and the outstanding personnel which would construct and operate the accelerator. Stanford University is situated in my congressional district and I have had numerous opportunities to observe the high quality of scientific research which is conducted there by some of the outstanding scientists of our time.

Stanford University has a long background of experience in the linear accelerator field. It dates back to the midthirties when the brilliant late Stanford professor, William Webster Hansen, discovered the rhumbatron. This development became useful in 1948 when the multimegawatt klystron was developed. This was another Stanford invention developed in 1937 by the Varian brothers working with Professors Hansen and Webster and research associates V. R. Woodyard and E. L. Ginzton. Though it is material to this hearing only insofar as it dramatizes the outstanding qualifications of Stanford personnel, I feel it should be mentioned that the klystron development played a vital role in the air superiority of the Allies during World War II, especially during the battle of Britain and also in antisubmarine warfare.

Since 1946, Stanford scientists can proudly point to a series of major scientific breakthroughs which have demonstrated the feasibility of the linear accelerator. Since 1946, 10 linear accelerators have been constructed at Stanford or under Stanford's direction. It is well known that several nations are either constructing or are considering construction of Standfordlike accelerators. In nearly all of these cases the large machines are either patterned after the Stanford machines, employ Stanford-trained personnel, or have borrowed Stanford members for restricted periods of time. I do not believe it

is an overstatement to say that no institution has had more to do with making the linear accelerator possible.

While the machine would be a national asset and available to qualified scientists from any institution, it is important to note that its location at Stanford would be with one of the outstanding physics faculties of the world. It is relevant to note that the physics department at Stanford has had six men named to the National Academy of Sciences since 1948, and two physics professors, one of whom is now at Oxford University, have been Nobel Prize winners since 1952.

Naturally, real estate is important in selecting a location for such an important piece of machinery. Stanford University has offered 400 acres of its campus as a site. Living and climatic conditions are considered ideal and constitute an unmatched environment for research. The site is centrally located to a rapidly developing electronics industry, the manufacturing and research facilities of the Lockheed Missiles System Division, Ames Laboratory of NASA, the University of California, the University of Santa Clara, San Jose State College, and San Francisco State College.

Geographically, the Stanford site cannot be surpassed, but I am sure that this committee will wish to give even greater weight to the superior quality of personnel which is available at Stanford to construct and operate this investment of $105 million in the future of our people.

To summarize, Mr. Chairman, let me say that the Hansen Laboratories at Stanford are now known as one of the world's foremost research centers in the field of microwave techniques. The university has at the present time the largest single group of men who have experience in developing a machine of the proposed type and are qualified to build and operate it.

We are fortunate indeed to have before us a proposal which ideally combines an excellent location with a high and readily available inventory of scientific knowledge and demonstrated ability. I sincerely urge the committee to approve Stanford's proposal and wish to thank you for hearing me today.

Representative PRICE. Are there any questions from the committee?

Chairman ANDERSON. I wonder if anything is going to be done to try to give title to the United States before this is built. Members of the Commission will recall that we had a proposal to do some building at Notre Dame and because it was private land we left it out of the research program this year. I would not want to be in the position of rejecting Notre Dame and taking on Stanford.

Representative GUBSER. Senator, that is a question, with your permission, I would like to defer to the representatives of Stanford University, who are present.

Chairman ANDERSON. Is there someone from Stanford who can answer?

STATEMENT OF ROBERT MOULTON, ASSISTANT TO THE PRESIDENT OF STANFORD UNIVERSITY

Mr. MOULTON. I am Robert Moulton, assistant to Dr. Sterling, president of Stanford.

Under the provisions of the will of the Stanford family, the Stanford land cannot be sold.

Chairman ANDERSON. Therefore, the Government could not get title to this land.

Mr. MOULTON. That is correct, sir.

Chairman ANDERSON. Do you know anything about what we would be up against in connection with this? We have turned down other universities where it is privately owned and refused to put facilities on these grounds. We turned down this one at Notre Dame in the last appropriation bill. Can you give us any reason why we should turn down Notre Dame which is a Catholic institution, and take Stanford, which is not connected with any church? You know what we would be into right away. Everybody would say that they rejected this Catholic institution and took on something else. There is nothing of that nature involved in it but how will you explain it?

Mr. MOULTON. It is our understanding that there is precedent for long-term leases at very nominal fees.

Chairman ANDERSON. For construction of a $100 million Government facility?

Mr. MOULTON. Perhaps not at that dollar magnitude, but at significant dollar levels.

Representative VAN ZANDT. If the gentleman will yield.

What is the nature of this lease? What kind of lease is it? Is it indefinite without compensation?

Mr. MOULTON. It was assumed that this would be part of the contract negotiations.

Chairman ANDERSON. Assumed that what would be?

Mr. MOULTON. The lease terms.

Chairman ANDERSON. What are they?

Mr. MOULTON. They have not yet been discussed.

Chairman ANDERSON. You do not have a proposal before the Commission?

Mr. MOULTON. For a specific lease?

Chairman ANDERSON. Yes.

Mr. MOULTON. No, sir.

Chairman ANDERSON. How can you consider the money if we do not know what the land cost will be?

Mr. MOULTON. It is understood that the length of the lease is not determined but that there would be no charge for the land.

Chairman ANDERSON. You do understand that this committee is being asked to vote $105 million. Would you not think part of the agreement would be where they are going to put the thing?

Mr. MOULTON. The location is specified.

Chairman ANDERSON. I understand. Suppose I said I would like to build a building out at 14th and H Streets—I hope there is a big one there—but I say these people own the land and I think they will make terms with me. Therefore, I will start constructing it. Do I understand that you have made a firm offer to the Atomic Energy Commission or have not?

Mr. MOULTON. We have made a firm offer with the understanding that there would be no charge for the land, Senator.

Chairman ANDERSON. What was the firm offer?

Mr. MOULTON. That there would be a long-term lease which would be mutually agreed upon and with essentially no charge, that is to say, a dollar a year or something of that sort.

Chairman ANDERSON. How long a term?

Mr. MOULTON. This was not specifically discussed.

Chairman ANDERSON. How long can you under the will, 49 years or 99 years?

Mr. MOULTON. Ninety-nine, I believe. This is not under the will, but under State law. That is the longest.

Chairman ANDERSON. I am not sure it is not in the will.

Mr. MOULTON. It may be both.

Chairman ANDERSON. I am not talking about the terms of the will. You will have to do under State law what is provided for in a will.

Mr. MOULTON. That is right.

Chairman ANDERSON. How long can you lease property?

Mr. MOULTON. Under State law 99 years.

Chairman ANDERSON. Mr. McCone, do you regard that as sufficient title?

Mr. MCCONE. Yes; I do. The basis on which we are discussing this matter with Stanford is a long-term lease, the exact term of years not definitely agreed upon, but at no cost to the U.S. Government for the use of the land. That is clearly understood by the officials of the university as the basis upon which, and the only basis upon which we will consider going forward with this project.

Representative PRICE. What do you have at Berkeley?

Chairman ANDERSON. That is a little different. That is a State institution.

Mr. MCCONE. That is a State institution. I believe there is no compensation for the land, although I believe the title to the land rests with the university.

Chairman ANDERSON. Mr. McCone, you were just out at Notre Dame making a fine speech. You are interested in that school. We all know it is a fine school. We felt that we had to eliminate a provision for some special money in this last appropriation authorization bill because it involved the construction on privately owned land and the expenditure of many millions of dollars on privately owned land.

I would feel very sorry if we turned Notre Dame down and turned around and did something at Stanford so that people could say it was the wrong basis for rejection.

Mr. MCCONE. I do not know the reason why the committee did not act on Notre Dame but the reason that I did not support the Notre Dame proposal, as I testified before the committee and stated this morning, was because it involved the building of a facility at a private university, and the same is true of a State university, in the absence of any Federal policy concerning the placing of facilities of that type on universities.

The issue was not in the case of Notre Dame, as far as I was concerned, the possession of the parcel of land on which the building was placed.

Representative PRICE. I could give you the reason why the committee did not act. We had no recommendation from the Commission on the project in this year's authorization bill and, therefore, we did not want to pick up a project which does have high priority but was not recommended to us, with this policy undecided.

That is the reason we did not act on it. We would have been in the position of putting it in the bill without a recommendation from the Commission.

Mr. McCone. That is right. I have not looked over my testimony but I think it was rather clear as to the reasons I advanced for not supporting the "Notre Dame" item. As you will recall, and as I said this morning, I am in favor of necessary Federal assistance of this type, but I think it must be worked out as a matter of policy rather than just a project here and there. (See p. 23.)

Chairman Anderson. You understand, Mr. McCone, that most of us, and I know I, are not at all opposed to this project, but would like to see it done.

I do not want to find myself in the position where we apparently take one attitude because we don't have a policy of building things on private land and then suddenly turn around and do it at Stanford—unless we do have some sort of policy on it.

I think the interests of the Government would be adequately protected by a long-term lease. Certainly the way science is advancing, this particular accelerator is not going to be used 50 years from now. We may have done some other things on similar pieces of land in the meantime.

I hope we might have an expression of a reason why this is all right and something else was not quite ready at that time.

I am only trying to make sure that we protect all the members of the committee against charges that they went out and were not thoughtful when they passed on one and not on another.

Mr. McCone. I differentiate between this high energy accelerator and a laboratory such as the one proposed at Notre Dame because this is a specialized tool for a particular area of research. The laboratory, while it might have been oriented toward a particular field of research, nevertheless had a more or less universal application.

For that reason I differentiate between the two.

Chairman ANDERSON. I think you have helped us a good deal. Therefore, the peculiar nature of this accelerator, the fact that you desire to have it located in a certain area and have a certain size and a certain length, makes it desirable to go ahead and construct it in the Stanford area?

Mr. MCCONE. That is correct, sir.

Chairman ANDERSON. Whereas the laboratory could just as well have constructed it in any one of 48 different State universities providing the preliminary work had been done there.

Mr. MCCONE. That is correct.

Representative PRICE. I want to thank Congressman Gubser for his testimony. If there are no further questions of him, he may be excused.

Now, we will resume with the testimony of Dr. Williams.

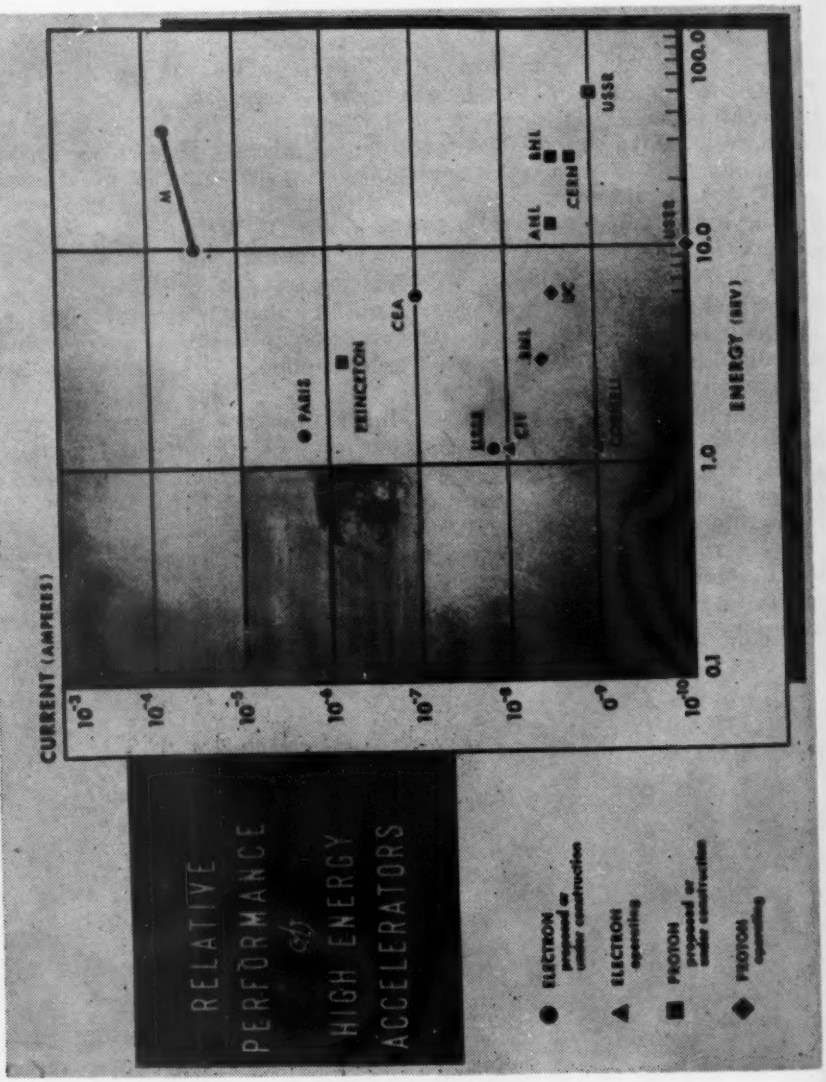
Dr. Williams, will you proceed with your statement?

Dr. WILLIAMS. Thank you, Mr. Chairman.

I would like to begin again in the middle of page 6 of my prepared statement since the material at the end of page 5 and the beginning of page 6 has been covered more than adequately, I hope, by the oral presentation while discussing the charts.

I should not leave you with the impression that energy is the only important characteristic of an accelerator. Of almost equal importance is the attribute of how many high-energy particles per second can be produced by the accelerator; that is, what is its capacity for producing a high current of particles?

The next chart shows graphically the currents produced by machines now in operation, those anticipated from machines under construction and those thought to be potentially available from machines which are under design.


RELATIVE PERFORMANCE of HIGH ENERGY ACCELERATORS
CURRENT (AMPERES)
ENERGY (BEV)
PARIS
ORSAY
CEA
CEA
ANL
ANL
CERN
USSR
USSR
ELECTRON proposed or under construction
ELECTRON operating
PROTON proposed or under construction
PROTON operating

We have plotted here on this chart vertically the current. I hope you will notice the compressed scale. The current scale is in factors of 10 million energy in the billion volts. We are confining our attention to an accelerator above 1 billion volts. The currents of this 10-billion-volt accelerator at Moscow is 10^{-10} amperes. Argonne National Laboratory here a few times 10^{-10}. The Cambridge accelerator 10^{-7}. The anticipated current from the Stanford accelerator, as you see, is at least 50 times greater than from any accelerator presently planned or in operation.

This is a very important attribute I wanted to bring clearly to your attention.

Passing then, to the bottom of page 6, I would like to say that one further attribute of the proposed machine is that the accelerated particles will be electrons. In many experiments they are a more useful "projective" than are protons because they make possible a detailed probing of the purely electrical structure of atomic nuclei and even of the elementary particles, protons and neutrons.

In fact, some of the most significant experiments of the last few years, representing a start in this direction, have been carried out at Stanford with their 700-Mev. machine.

The point that we would like to emphasize is that an electron accelerator which has the combination of high energy and high current would make possible the continued study of nuclear structure in greater detail. Furthermore, the capabilities of the Stanford accelerator would be unique for the foreseeable future.

The 10 to 15 Bev Stanford linear electron accelerator will be described in detail later by Dr. Ginzton. For the present, I would like to give you a general description of its nature.

This is an artist's conception of this machine in which these two tunnels extend 2 miles in length, this inset being a cross-section of the two tunnels. (See Ginzton's statement, p. 156.)

The larger one is 24 feet across and is required to house the klystrons and the electronic gear. The smaller one, 10 feet across, is required to house the accelerator. They are separated by 35 feet of earth so that personnel may operate and maintain equipment in the large tunnel while the accelerator is running in the small one in order to protect themselves against the radiation.

The accelerator consists of essentially a long pipe. Electrons are introduced at the end of that pipe, are accelerated by the electric field set up in that pipe by the klystrons and emerge at the end of that pipe, having traveled 2 miles with an energy of 10 billion electron volts, or more.

How much more depends upon the power delivered to that pipe by the 240 klystrons attached to it. Dr. Gintzon will explain this in more detail to you at a later time. When they leave the end of this pipe they enter a system of magnets so that they may be deflected in a variety of areas.

This picture should not contain this large area here. The picture was drawn for the original Stanford proposal of a 45 Bev. They will enter three possible areas, two within this house and one in an outdoor yard.

Representative VAN ZANDT. Doctor, will you translate the energy into speed?

Dr. WILLIAMS. The speed of an electron of this energy is so close to the velocity of light as to be insignificantly different. That is 186,000 miles per second. The speed is acquired very rapidly and reaches that value in the first few feet of the accelerator. The additional energy given to it simply increases the mass of the electron.

Representative WESTLAND. Doctor, how much do you need in terms of kilowatts?

Dr. WILLIAMS. The total connected electrical load in this phase that we are talking about today is 60,000 electrical kilowatts.

Chairman ANDERSON. Will you use it steadily?

Dr. WILLIAMS. That will be the load in operation. The plans are to operate this machine 24 hours a day.

Chairman ANDERSON. You might as well build an atomic plant there.

Representative PRICE. Is there any question of a power supply?

Mr. MCCONE. No, there is no question.

Dr. WILLIAMS. I would like to turn then, to the middle of page 8 in my prepared testimony since what I have just said is contained on pages 7 and 8.

Chairman ANDERSON. You discussed this Washington situation a minute ago and said it would be probably more expensive to build it. With 2-mill power at Bonneville as against 6 or 7 mills P. G. & E. will charge you, how much would you save a year if you operated 24 hours a day at 60,000 kilowatts?

Dr. WILLIAMS. I have not made that calculation. I would submit it for the record. It would be a significant amount and I would be happy to make the calculations and provide it to you, sir.

Chairman ANDERSON. Thank you.

Dr. WILLIAMS. If I may then proceed, the availability of a site, at no cost, located only a few minutes away from the Stanford campus, is particularly fortunate. It will thus be possible to utilize the Stanford scientific staff in the design, construction, and operating phases of the project, which could not be effectively done at any other location.

Next, I would like to describe the Commission's review of the project. As is our practice, the Commission has subjected the proposal to an intensive review by its own scientific staff and by outstanding scientists in the field. This review during 1958 indicated enthusiastic agreement on the technical feasibility and desirability of the project and the special competence of the Stanford staff. The AEC did not carry out any further independent review because of the thoroughness of the NSF and SAC–GAC review panels. (See pp. 235 and 527.)

Following the scientific review of the Stanford proposal the Commission employed the firm of William Brobeck & Associates to review the engineering concepts of the proposal and to analyze the estimated costs.

Brobeck employed Kaiser Engineering to assist his firm in assessing the construction costs. The Brobeck analysis was finished in June 1958 and serves as the base upon which our estimates of the cost of the present construction proposal was made.

Subsequent to the submission of the Brobeck report, further refinement was made to the cost estimates by consultation between the Stanford staff and the AEC staff. The condensed version of this

latest analysis, in major categories, is presented in the data sheets which you have before you.

Full authorization is requested at this time since the principal features of the machine are established now and do not require that one await completion of design. Furthermore, full authorization now will give Stanford assurance of the Government's intentions to carry the project through to completion.

The accelerator will, of course, upon completion, be operated as a national facility. Stanford University recognizes this fact by suggesting the creation of a board of directors, to be responsible to the president of Stanford, which will establish basic policies for the project, select its director, and otherwise control the activities of the project to guarantee its role as a national facility. The board shall consist of prominent scientists and administrators from several universities and research establishments in the United States.

Mr. Chairman, with this background I would like at this time to submit for the information of the committee and for the record an elementary statement of the fundamental principles of high-energy physics.

Representative PRICE. Without objection, it will be received for the record.

(The document referred to is in app. 3, p. 539.)

Dr. WILLIAMS. As I have said before, the fundamental goals of the study of high-energy physics can only be attained by using accelerators as tools with which to probe the nucleus. This interrelationship between accelerators, high-energy physics, and the nature of all matter is the subject of a primer which was prepared for the SAC–GAC panel.

We in the Commission have found this elementary statement of a most complex subject to be accurate and understandable. We would like to request that this document be included in the record since we feel that all those who have the opportunity to read the record of these hearings will want to study the excellent report with special care. Its content supports the basic justification of the present proposal that must necessarily rely on its contribution to the scientific knowledge.

Following any questions which you may care to ask, Dr. Haworth is prepared to expand on the material given in the elementary statement and to explain the relationship of the proposed Stanford accelerator to the problems at the forefront of high-energy physics.

Representative PRICE. Thank you, Dr. Williams. Are there any questions of Dr. Williams?

Mr. Van Zandt?

Representative VAN ZANDT. Doctor, have the Brobeck people submitted an estimate of cost on the present proposal?

Dr. WILLIAMS. Not on the existing proposal, which is modified from the one which they analyzed principally by reducing the number of klystrons from 480 to 240.

Representative VAN ZANDT. In your testimony you state that the beam energy will be increased to 45 Bev. Can you give us an estimate of the cost of the increase?

Dr. WILLIAMS. To do this at the present state of the art of klystron development we anticipate the need to put four times as many klystrons on it. That is going from 240 to 960. We hesitate to give you an

exact estimate simply because it won't be done until the need arises, which will be many years from now after construction and operation.

At that time the capability of klystrons may be different in cost, but we can only give you an order of magnitude estimate by referring back to the Brobeck original size which showed that the cost of going from 15 to 25 to 45 was of the order of $10 million.

This was a right order of magnitude of cost, $10 million more to go from whatever the machine is operating at to 45 Bev.

Representative VAN ZANDT. Then we can expect the Commission will request authorization?

Dr. WILLIAMS. We would request authorization for any extension past the 240 klystron system that we are presently proposing to you.

Representative PRICE. How much difference is there in power consumption as you move up?

Dr. WILLIAMS. The power consumption will increase linearly with the number of tubes, which is a factor of 4, and also the power output of those tubes will have to grow in time by a factor of 2.

The radio frequency power consumption will increase by some factor of 5 to 10.

Representative PRICE. Dr. Williams, were comments obtained from outside experts on the Stanford accelerator as was done in the MURA proposal in 1957?

Dr. WILLIAMS. We did not get them from as many but we got them from the order of half a dozen people.

Representative PRICE. Could you provide that for the committee files?

Dr. WILLIAMS. We would provide that. We would protect the anonymity of our reviewers, of course.

(A summary of the material furnished follows:)

SUMMARY OF OUTSIDE TECHNICAL REVIEWS OF THE STANFORD PROPOSAL FOR INCLUSION IN THE STANFORD ACCELERATOR HEARINGS

The original Stanford proposal (April 1957) was submitted to seven outside reviewers for comment with particular emphasis to be placed on the technical feasibility, research potential, and the soundness of the cost estimates for the machine, as well as the technical abilities, size, and overall competence of the proposed staff. A summary of their replies follows:

1. No question about the technical feasibility of the proposal. Circular machines impractical above 8 Bev. Suggest modifying AGS to make a 12–15 Bev. electron machine, or using the gamma rays from the AGS which may provide a well-collimated high-intensity source. Has high regard for Stanford people. Main reservation: Is the high cost justified?

2. Technical feasibility undoubted. Research potential very great. Would prefer over MURA machine if choice is necessary. Stanford people of highest competence. Questions choice of site in that flat area would be better.

3. Enthusiasm and ability of Stanford group greatest asset. Mentions short duty cycle compared to synchrotron. Gives an off-the-cuff opinion that 50 Bev. synchrotron would be cheaper. Recommends approval.

4. Technically feasible. Would provide diversity compared to our other accelerators. Technical staff without peer. Gives proposal strongest endorsement.

5. Doesn't question technical feasibility, but characterizes proposal as "brute force" approach. Claims CEA will have current only one-third less than Stanford and a duty cycle 1,000 times better. Questions Stanford's ability to develop klystrons to necessary power rating for stage II. Scientific value of such a machine could be better assessed when CEA results are in. Is worried that undertaking this project would result in inadequate support for other high energy facilities.

6. Design is feasible. Odds good that research potential is high. Limits to quantum electrodynamics and possibility of new particles are very worthwhile experiments.

7. Thinks Stanford machine would be very useful, although would give priority to a high current proton accelerator.

(NOTE.—Comments on the proposed Stanford accelerator prepared by Dr. T. A. Welton, consultant to the Joint Committee, are contained in app. 4, p. 550.)

Representative PRICE. That will be done. What plans have been developed for the use of the accelerator on a national basis with participation by scientists from other universities and laboratories?

Dr. WILLIAMS. As I said in my statement on page 9, there will be formed a board of directors with various subboards that will determine that the machine shall be used in a sensible way to do experiments which are agreed upon by the scientific fraternity are meaningful and will determine in that sense the people that will use it and what kind of time they have available and keep currently informed on the program and do the programing on the machine.

We have every assurance that this will be considered as a national facility.

Representative PRICE. In other words, this board of directors will set up the programing for the use of the accelerator.

Dr. WILLIAMS. Yes. It will have to do that currently and meeting often to keep current with the affairs.

Representative PRICE. Mr. Bates?

Representative BATES. I did not hear all of the questioning, but I was interested in your comments on page 9, and to see what their responsibility and authority is contrasted to the AEC. As I read this, it indicates that this board of directors is responsible to the president of Stanford which will establish basic policies for the project.

So, the directors will otherwise control the activities of the project to guarantee its role as a national facility. Just from reading that, it would appear that the Federal Government is completely out of the picture.

Dr. WILLIAMS. It would be in terms of day-by-day operations since the Commission does not operate such facilities. It administers them. This group will have to receive its operational budget from the Government and this is the principal control. There is no question in my mind that we do not want to enter as a Commission or a division of the Commission into the day-by-day operation. But we will have the control through the operational support of this group.

We will have our concurrence in their actions and it will be required in order to get continued support.

Representative BATES. It is basic policy.

Dr. WILLIAMS. It is the same system that is used at Brookhaven and Argonne and Berkeley which we have found so successful.

Representative BATES. That is what I wanted to have put in the record, to indicate that this is not different.

Representative PRICE. On your point, will it be the same situation?

Dr. WILLIAMS. In principle, yes. In details I think one would find differences. In principle it is a concurrent policy and management but the day-by-day operation has to rest in that locality.

Mr. RAMEY. In the case of Argonne and Brookhaven, following along Congressman Bates' suggestion, it is my understanding that there was agreement between the Commission representing the Fed-

eral Government and the Argonne National Laboratory, operated by the University of Chicago, as to what these basic policies are and what the basic organizational setup would be for the operation of such a large facility with so much interest from a regional and national standpoint. Would that be the case here?

Dr. WILLIAMS. There are boards even at the Argonne. There is the advisory board of Argonne of which I happened to be a member in years past, who acted as an outside board advising the contractor, the University of Chicago.

That advice was filtered, relayed to the Commission and the policy developed in this consultative way. I don't feel any difficulty about the basic control we have because the Government has the money control.

Representative BATES. I understand that the Government will provide the money later on as it is now, but nevertheless, the basic policies will be determined by the university.

Dr. WILLIAMS. That is unfortunate language, but in view of our present experience with other similar institutions, I would feel we have no real difference.

Representative BATES. I wonder if Mr. McCone would comment on that point.

Mr. MCCONE. Yes. In the operation of the laboratories that are considered as national institutions, the operating contractors are subject to the overall policy direction of the Commission. The purpose is to have them exercise operational control but at the same time to have the Commission's philosophy of having these national laboratories available to all of the institutions and the scientists that need them for their particular work.

If you would visit, as you have the cyclotron at Berkeley you would find that there are groups from many universities conducting experiments concurrently. The detailed arrangements of how that is worked out is handled by the group at Berkeley, but it is subject to the overall policy direction of the Commission. (See app. 10, p. 644.)

Representative PRICE. Dr. Williams, the proposal originally submitted by Stanford covered a 15 to 25 billion electron volt accelerator, while this present proposal refers to an energy range from 10 to 15 Bev.

Why was the energy decreased?

Dr. WILLIAMS. The energy was decreased after intensive reviews by NSF and by the GAC panel. They recommended a cutback to 10 to 15 Bev. accomplished by reducing the number of klystrons. In this we in the Commission heartily concur. The reasons for their recommendations are both scientific and economic.

First, there is a saving of money, but secondly, we want to build a machine which will be able to attack the problems which we see now to be important. Simultaneously with that, we have in this facility proposed to you the possibility of expansion to the higher energy at a later time with additional cost if it is warranted then on the basis of the scientific need.

Representative PRICE. The potential that you talk about runs all the way up to 45 Bev.

Dr. WILLIAMS. Yes, sir.

Representative PRICE. What would be the cost of stepping it up to 45 Bev.?

Dr. WILLIAMS. We are not in a position to give you an exact figure but the order of magnitude of cost is around $10 million for the additional 1 klystrons as we see them today.

Representative PRICE. What specific type of research and development work is to be done with the $18 million referred to in the proposal since the accelerator is understood to be based on proven concepts?

Dr. WILLIAMS. One surely could build an accelerator made up of 40 of the existing operating prototypes. We feel this would not be the proper way to do that simply because that would involve building a machine with components which were not designed for 24-hour-a-day reliable operation with minimum maintenance.

It would also not allow the further development of the output capabilities of klystrons. There would be two major efforts in this research and development. One is the improvement of reliability of components other than klystrons, and further, the improvement of the reliability of the klystrons and their power output.

Representative PRICE. Are there any further questions of Dr. Williams, Mr. Van Zandt?

Representative VAN ZANDT. Doctor, getting back to the cost factor, how much money has been spent already in the development of the design?

Dr. WILLIAMS. In the existing 730-Mev. linear accelerator?

Representative VAN ZANDT. Yes.

Dr. WILLIAMS. This is supported by the Office of Naval Research. I do not have an accounting for it. Dr. Ginzton clearly is prepared to answer that question, or his colleagues. May I call on them, please?

Dr. GINZTON. The cost of research and development in the program over a period of years dating back from 1949 to the present is $10 million to date, from ONR, Air Force contract support and AEC for research, development and operation of the machine.

The original machine was built with money provided by ONR at a cost of $1.5 million. That is the present machine we have in operation at Stanford today. The research and development continued on and it is impossible to separate the cost of specific development from the continuous operation of research and operation. It is contained within the $10 million mentioned to start with.

Representative VAN ZANDT. It is proper to say then that the Navy has already invested $10 million in this project?

Dr. WILLIAMS. In the buildup to this point.

Representative PRICE. This brings up a question I would like to ask here. Will the technology available from the operation of this machine be of value to the military program?

Dr. WILLIAMS. The basic knowledge to be learned by this machine is knowledge in nuclear physics. It is quite clear on the basis of past history that the development of technologies in high-energy physics always have applicability sooner or later to the modern technology.

In particular, the development of these klystron tubes may very well make them more useful for communication devices which are of use to the military.

Representative PRICE. Are there any further questions?

If not, do you want to turn the stand over to Dr. Haworth?

Dr. WILLIAMS. Yes, sir.

STATEMENT OF DR. LELAND J. HAWORTH, DIRECTOR, BROOKHAVEN NATIONAL LABORATORY

Dr. HAWORTH. Mr. Chairman, it is a privilege and a pleasure to speak to you this afternoon on a matter of such transcendent importance in our scientific program. I should like to preface my technical discussion by three general remarks. Firstly, the things that I shall say gain their significance not from my individual opinions but because to the best of my belief they represent the composite views of the many distinguished scientists active in this field. They formed the basis for the recommendations of both the NSF panel on high-energy accelerators and the joint SAC–GAC panel on high-energy physics.

Secondly, in the time available, it will be possible to give only a very brief discussion of the subject which, as you know, is extremely complex and difficult to understand, even for the most highly trained specialists.

Thirdly, much, or even all, that I shall say has been known to you before—from your reading, from your various discussions, and from testimony such as that presented in the hearings on the Commission's physical research program held before the Subcommittee on Research and Development last year. I shall attempt, however, to put some facts before you in organized and summary form in the hope that I may show you wherein lie some of the most vital problems that we seek to solve and how the proposed linear accelerator can contribute importantly to the solutions. I have prepared a detailed technical statement which has been handed to your staff. However, because of its technical nature and in the interests of saving time I shall read it only in part and talk extemporaneously from charts on the more technical aspects.

Representative PRICE. You may do that, Doctor. Without objection your complete statement will be printed in the record.

STATEMENT OF LELAND J. HAWORTH, BROOKHAVEN NATIONAL LABORATORY,
AT THE STANFORD ACCELERATOR AUTHORIZATION HEARINGS
BEFORE THE JOINT COMMITTEE ON ATOMIC ENERGY

Mr. Chairman:

It is a privilege and a pleasure to speak to you this morning on a matter of such transcendent importance in our scientific program. I should like to preface my technical discussion by three general remarks. Firstly, the things that I shall say gain their significance not from my individual opinions but because to the best of my belief they represent the composite views of the many distinguished scientists active in this field. Secondly, in the time available, it will be possible to give only a very brief discussion of the subject which, as you know, is extremely complex and difficult to understand, even for the most highly trained specialists. Thirdly, much, or even all, that I shall say has been known to you before--from your reading, from your various discussions, and from testimony such as that presented in the Hearings on the Commission's Physical Research Program held before the Subcommittee on Research and Development last year. I shall attempt, however, to put some facts before you in organized and summary form in the hope that I may show you wherein lie some of the most vital problems that we seek to solve and how the proposed linear accelerator can contribute importantly to the solutions.

As you are quite aware, the search for basic understanding of the atomic nucleus and of its particles and its internal forces lies at the frontier of modern science. As is well said in the statement of fundamental principles alluded to by Dr. Williams, scientific frontiers are always moving. At present

the most basic lie at opposite extremes -- in the indefinitely large and in the sub-microscopically small. It is with the latter that we are concerned today.

Man's everlasting search to understand the universe around him began with gross phenomena -- with things that he could see and hear and feel and smell. In the next step he devised instruments to measure length and time and mass, and thence force and energy and other quantities -- still dealing with matter in the gross. As time went on, he recognized that there must be a finer structure. With microscopes and other tools, he could observe details beyond the power of his senses used directly. He began to search for some underlying pattern. Instinctively, he felt that the vast complexities with which he was surrounded could be explained in terms of various combinations of fairly simple building blocks. There has been a constant search to find and understand those fundamental blocks.

Until fairly recent times the recognizably different substances -- water, air, salt, various minerals, and so on -- were thought to be the fundamental constituents of matter. Further investigation showed that the almost infinite varieties of molecular substances are compounded from less than one hundred kinds of elementary atoms. The recognition of this elementary structure and the identification of most elements was one of the great scientific triumphs of the nineteenth century.

Still further study showed that the atoms in turn possess an inner structure. Brilliant research culminating in that of Bohr and Rutherford showed each atom to be a tiny positively charged nucleus carrying nearly all the mass surrounded by one or more electrons whose number characterizes the individual element and determines its chemical and many other properties. The regularity of nuclear progression, the phenomena of natural radioactivity,

and later the studies of cosmic rays showed that even now the ultimate had not been reached, that the nucleus itself must have a structure, that still more fundamental particles must be contained therein. The study of the nucleus, begun in earnest only a few decades ago, quickly showed these particles to be protons and neutrons bound together in various combinations by enormous attractive forces. A major effort in the intervening period has been to dissect the nucleus to determine the nature of the forces, the various energy combinations and the detailed structure. In the process, it began to be apparent that the end had not been reached, that the nucleons themselves, the proton and the neutron, also have a structure and that associated with them in transient form are many other particles. Thus as problems have been solved and questions answered, new questions have arisen. It is toward answering these questions that ultra high energy physics is directed.

Before turning to detailed consideration of the situation, let us remind ourselves of a few generalizations. Throughout our studies, a number of general physical laws have always been obeyed. Important among them are the various conservation laws -- the conservation of energy; the conservation of momentum, including angular momentum; the conservation of charge, and so forth. From time to time, they have required modifications or extensions. For example, on the atomic scale it was necessary to broaden the law of conservation of energy to include mass as well as energy, relating them through the Einstein equation, $E = Mc^2$. We should also remember that many parameters such as energy and spin are quantized; they can take on only certain discrete values and hence changes in them must also be discrete. The situation might be likened to standing on a flight of stairs; only certain discrete positions and changes in position are possible. There are also certain selection rules telling us that some changes are much more probable than others and that many

seemingly possible changes are forbidden for one reason or another. Another great generalization is that the energy of a system tends to degrade, that any system will seek to change itself to a state of lower energy if that is possible within the various laws. The total probability of change is affected by the strength of the forces involved, by the amount of energy released and by the selection rules.

We should also look briefly at our means of examining the nucleus. By far the most important have utilized those schizophrenic tools, particles and waves. It has been one of the great triumphs of modern physics to understand their dualism. For example, the classical electromagnetic wave is simultaneously a particle called a photon, whose energy is proportional to the frequency of the wave. Conversely, what are classically thought of as particles -- electrons, protons, and so forth -- have in motion many of the characteristics of waves that can be diffracted, that undergo phase changes, and so on. The wave length of these matter waves varies inversely with their energy. These particles, as I shall call them collectively, have two general uses in studying nuclear structure. First, they are carriers of energy with which to produce changes in the structure, to create new particles, and so forth. Secondly, and importantly, they serve as probes with which to see details of structure just as light is used to examine macroscopic matter and X-rays and slow neutrons are used to study crystals by diffraction. As one has delved deeper and deeper into the atom and the nucleus, it has been necessary to use evermore energetic particles not only to produce more energetic changes but also to achieve the shorter and shorter wavelengths necessary to distinguish finer and finer details. Both the interaction processes we study and the fineness of detail we seek now require particles in the multi-billion volt range of energy. It is in providing these very energetic particles that accelerators play their vital role.

In the units that are used, the electron is the base. Its mass is 1 and its charge is -1. The charge of the proton is +1. Its mass and that of the slightly heavier neutron are approximately 1840. Energy is measured in millions of electron volts, MEV, or billions of electron volts, BEV, corresponding to the energy acquired by unit charge in passing through the indicated difference of potential. The mass of the electron has an equivalent energy of about one-half an MEV, that of the proton or neutron slightly less than one BEV.

A word of caution about energies. When a moving particle strikes a stationary one, only part of its energy is available for producing interactions in the center of mass system of the interacting particles. This is because in the laboratory system part of the energy must go into conservation of momentum. The relative reduction in the energy available increases with the energy of the moving particle. It is serious at the multi-Bev energies with which we are concerned, slightly less so for moving electrons than for protons. (See Figure 4)

Now let us examine the atomic nucleus, firstly what I shall call the classical model of the nucleus, one with which you are familiar. It can be described, though only partially explained, in terms of three force laws and a few elementary particles. Holding the protons and neutrons or nucleons together within the nucleus are enormous forces known as strong forces that decrease rapidly with distance so that they are negligible outside the nucleus. These are responsible for the formation of all known nuclei, for the binding energies involved, and for many other processes. In a second force group fall the electromagnetic forces exerted between electric charges. They are responsible for holding together the external structure of the atom as well as playing a role within the nucleus. If one assigns unit value to the strong forces then at intranuclear distances, electromagnetic forces have a strength

of about one one-hundredth, though they decrease with distance much more slowly. (See Table I). In a third group are the so-called weak forces taking

Strong (Nuclear) Forces	1
Electromagnetic Forces	.01
Weak Forces	10^{-14}
Gravitational Forces	10^{-38}

Table I - Relative strengths of elementary forces.

part in radioactive decay both of compound nuclei and of unstable elementary particles. They are very weak indeed, only about one one-hundredth of a trillionth (10^{-14}) of the strength of the strong forces. You have heard much about weak coupling forces in connection with the brilliant theoretical prediction of Lee and Yang, later verified experimentally, that the conservation of parity does not hold in weakly coupled interactions. For completeness, I shall also list the gravitational forces although they play no role within the nucleus, since their strength is only about 10^{-38} of the strong forces. We shall say no more about them.

Where we have sufficient knowledge, it is found that the force fields are associated with particles carrying the force. This is best understood in the case of electromagnetic forces. Here we know that each charged particle is constantly emitting and reabsorbing tiny bundles of electromagnetic energy or photons. The process of emission and absorption occurs so rapidly that it cannot be detected, even in principle, so that the energy of the particle can be considered to be constant and the process is described as virtual. The exchange of virtual photons between charged particles accounts for their mutual interaction. By introducing energy from outside the particle, real photons can be created from virtual ones and energy is radiated. All so far

observed electromagnetic interactions can be accurately described in terms of this hypothesis.

Reasoning by analogy, as is often done in physics, the Japanese physicist Yukawa in 1935 postulated a new particle playing the same role in strong forces as do the photons in electromagnetism. In contrast to the massless photons, this particle would have a rest mass which he calculated to be from 200 to 300 times that of the electron. Hence he called it the mesotron (designating a particle of intermediate mass), a name that has since been shortened to meson. The experimental discovery in the late 1940's of the pi meson, or pion, with a mass of 273 was a triumph for the theory. To create a real from a virtual pion requires about 135 Mev of energy in the center of mass system.

The mechanism by which weak forces are exerted is not understood at present.

Our simple model requires one more particle. In radioactive decay, there is in general the disappearance of energy and momentum. To account for this there was postulated a chargeless, massless neutral particle, the neutrino, or little neutral one as it was poetically called by Fermi. Its interaction with other particles is almost vanishingly small. An enormous flux of neutrinos from the sun passes through the earth as though it were not there; only one in a million-million suffers any interference.

Thus our simple model has particles of four general classes; the heavy nucleons, the light electrons and neutrinos, the intermediate mesons responsible for nuclear forces, and the photon, the carrier of electromagnetism. By 1950 all of these facts were known. Only the neutrino had not been observed directly.

There was additional information not necessary to the simple model. The mu meson, or muon, resulting from spontaneous decay of the pion and itself

decaying into an electron and a neutrino had been observed. Within our subdivisions, the muon, of mass 200, should be classed with the electron rather than the pion since it is not a carrier of strong forces and has a characteristic spin and other properties similar to that of the electron and neutrino.

Another whole family, the anti-particles, had been theoretically predicted and partially observed. By the quantum theory each particle save the photon should have an anti-particle with which it annihilates on collision with the emission of lighter particles that carry off the energy. The anti-electron, the anti-pion, and the anti-muon had been observed, first in cosmic rays and later in the laboratory. The anti-nucleons were observed much later, in 1955, when energies above their production threshold became available at Berkeley.

In the early 1950's a whole new chapter was begun. A multitude of new and unexpected particles were found, first in cosmic rays and later in those laboratories having billion volt accelerators. These are shown in Figure 1 and Table II, together with our earlier particles. They fall into two of our general classes. A group of heavy mesons -- designated K -- has a positive and a neutral member together with their anti-particles. They decay into various combinations of pions, muons, neutrinos and their anti-particles. The members of the second group are heavier than the nucleons, and so far have been created from them. These hyperons, as they are called, occur in various groupings, a single neutral "Lambda", a negative and neutral pair of "Xi's", and a positive, neutral and negative triplet of "Sigmas". They decay into other heavy particles plus a pion or a photon. In keeping with theory, each should have its corresponding anti-particle, but so far none have been observed. Since the total number of heavy particles must be conserved, creation of new particles must be done by making particle-anti particle pairs. Sufficient

energy for this process is not yet available (See Figure 4). (In principle a hyperon-antihyperon pair could be made by bombarding protons by anti-protons.)

All of these new particles were given the generic notation of strange particles, not from their unexpectedness but because their lifetimes, the periods of their existence, were much longer than could be explained by existing theory. They were all formed in strong particle interactions in the fleeting time required for a bombarding particle to penetrate a nucleus. By the laws of reciprocity one would expect them to decay in equally short times. Instead they live long enough to travel distances measured in centimeters or even meters, as much as a million billion times longer than expected. Two of these strange particles are always produced together, a phenomenon known as associated production. This fact has given the clue to an explanation of their strangeness in terms of a conservation law. A property known as strangeness having both positive and negative values can be deduced and values assigned from the occurrence of these particles in singlets, doublets and triplets that differ from the arrangements of nucleons and pions. The various values of this strangeness are indicated in Figure 1.

Theory requires that strangeness be conserved. To make this true the positive and negative strangeness must be balanced. Hence, at least two particles must be made together. Once having been created and separated from its mate a particle can decay only by processes resulting in products of equal total strangeness. In only one case, the lambda, is this energetically possible and there the lifetime is quite short. Hence with this exception the particles cannot decay by strong force interactions but live until weak coupling forces, not involving strangeness, can cause them to decay.

It is important to know the geometry of the individual particles, their size, their shape, the distribution of their charge, their magnetism, and so

forth. Numerous possibilities can be conceived. Some are indicated in Figure 2 where density of shading indicates the density of the property in question. Such information can be obtained the most directly by the scattering of particles. For this purpose electrons or photons are the best. The interacting forces are well understood. Furthermore, since they are relatively weak, the nucleus is much more transparent than to strongly interacting particles and one can look inside. For complex nuclei, for protons, and for neutrons, we have some internal information. The most direct and precise has been obtained by scattering electrons of several hundred MEV produced in the present Stanford linear accelerator. From such experiments it has been found that in heavy nuclei electric charge is distributed almost uniformly from the center outward through a volume almost proportional to the number of nucleons contained. Beyond that point, the charge distribution falls off quickly to a zero value over a thin shell of the same thickness for all nuclei. This distribution is roughly that of Model C of Figure 2 and is shown in graphic form for the gold nucleus in Figure 3. (In lighter nuclei the central core disappears, the density decreasing from the center out -- see Model B.) Similar experiments on the proton have indicated a charge distribution starting from a large value at the center and falling steadily to zero value at the edge as shown in Model B and the second graph of Figure 3. (In the latter the scale of density is compressed tenfold compared to that for the gold nucleus.) The magnetic distribution in the proton and also in the neutron has a similar form. The shorter wavelengths accompanying much higher energy electrons are badly needed for studying finer details.

Summarizing this brief description, we see that we are confronted with a bewildering situation. Twenty-two elementary particles have been observed and nine additional ones have been predicted. With a few exceptions, we know

discouragingly little about them. To be sure we know their charge, their spin, their mass, their strangeness. We know something of the circumstances in which the transient ones can be produced and in what numbers. We know something of their interactions with other particles but there are enormous gaps. We have little knowledge of their internal structure.

There are innumerable unsolved problems. The structures and properties of the various particles must be much better known. We must have far better understanding of the interacting forces. We must search for new and unexpected particles and new phenomena. The list is almost endless.

Our knowledge can be effectively increased only through the use of ultra-high energy accelerators of diverse capabilities. The spectacular increase in proton accelerator energies in recent times has somewhat obscured the fact that many other parameters are also quite important. We must have electrons as well as protons; we must have intensities great enough to permit rapid observation of the various direct processes and to produce copious quantities of all transient elementary particles for use in secondary interaction studies; we must have sharply focussed beams and flexibility in time and space to suit the various purposes.

There is an especially acute need for very high energy electrons in large intensities and in well focussed beams. Because of easier and cheaper adaptation to circular machines, protons have been produced at energies far above those available with electrons. In contrast to the proton case where 6 Bev has been available and 30 will soon be reached, electron energies have so far been limited to 1 Bev. An important step that will fill an urgent need is being taken by construction of the 6 Bev Cambridge Electron Accelerator (CEA). However important though its potential contributions, there will be a vital need for higher energies, far higher currents, and much more sharply

focussed beams than it will be able to provide. The linear accelerator proposed will effectively meet these requirements. In its initial form it will have twice the energy and some 50 times the intensity of the CEA. As in all linear accelerators and in contrast to the circular machines, a full strength sharply focussed beam will emerge into free laboratory space where it will be quite accessible and can be used in many different ways. As time goes on and need arises, the energy can be increased (to as much as 45 Bev) both by increases in the power of the driving klystrons and by adding klystrons at relatively modest cost. By virtue of this flexibility, it can belong to more than one generation of machines.

Let us examine some of the more specific applications.

The machine will be a far more copious source of anti-nucleons and strange particles than any in the present program, which is confined to lower intensity pulsed circular machines (See Figure 5). Even though electrons, and the photons they produce, are less efficient than are protons as producers of most particles, the Linac will still far excel. The high energies and intensities to be available will make possible significant extensions of secondary interaction studies, especially with particles otherwise too rare to be so used.

But the primary scientific interest in this machine lies in studying directly the specifics of electromagnetic interactions. The production of secondary particles is by a different mechanism than with protons and one that seems simpler because we have a better understanding of electromagnetic than of nuclear forces. The production of all known strnage particles by the electromagnetic interaction at energies well above their thresholds should yield extremely valuable information concerning the production processes. It is also possible that new and as yet unknown particles will be produced. Especially interesting is the possibility of the direct electromagnetic

production of weakly interacting particles not hitherto observed. The very high intensities expected are essential to any search for such inevitably rare events.

The unique potentiality of the proposed accelerator lies, however, in the possibilities it affords for structural studies of elementary particles. A 12 Bev electron striking a proton has a wavelength only about one-sixth that of the highest energy electrons used so far. Indeed, this wavelength is only about one-twentieth of the radius of the proton and the proton structure could in principle be studied to features of this size. The structure studies can be of two general sorts. Elastic scattering experiments can extend those described earlier to give more detailed information on the structure of the nucleus and of the proton and the neutron. In inelastic interactions where secondaries are produced, information can be gathered as to the structure of both the struck and of the secondary particle.

Perhaps most important of all the possibilities is a very general consideration. Inherent in all the experiments described, and in others conducted for the purpose, is the study of the electromagnetic interaction itself. It is quite possible that at the very short distances involved the laws of quantum electrodynamics may be altered or even fail completely. Indeed the results of such experiments could raise questions of great philosophic and scientific interest. Under certain circumstances, the question might be raised of a radical revision of our concept of space itself. At sufficiently short distances do the axioms of Euclidean geometry fail? Can even the notion of continuity of space itself be maintained? Even should such conceivable anomalies not be found, information on these points would be most valuable.

In addition, it should, of course, be pointed out that in all previous experience such significant extensions in experimental possibilities as here proposed have led to completely unanticipated results and opened up new realms

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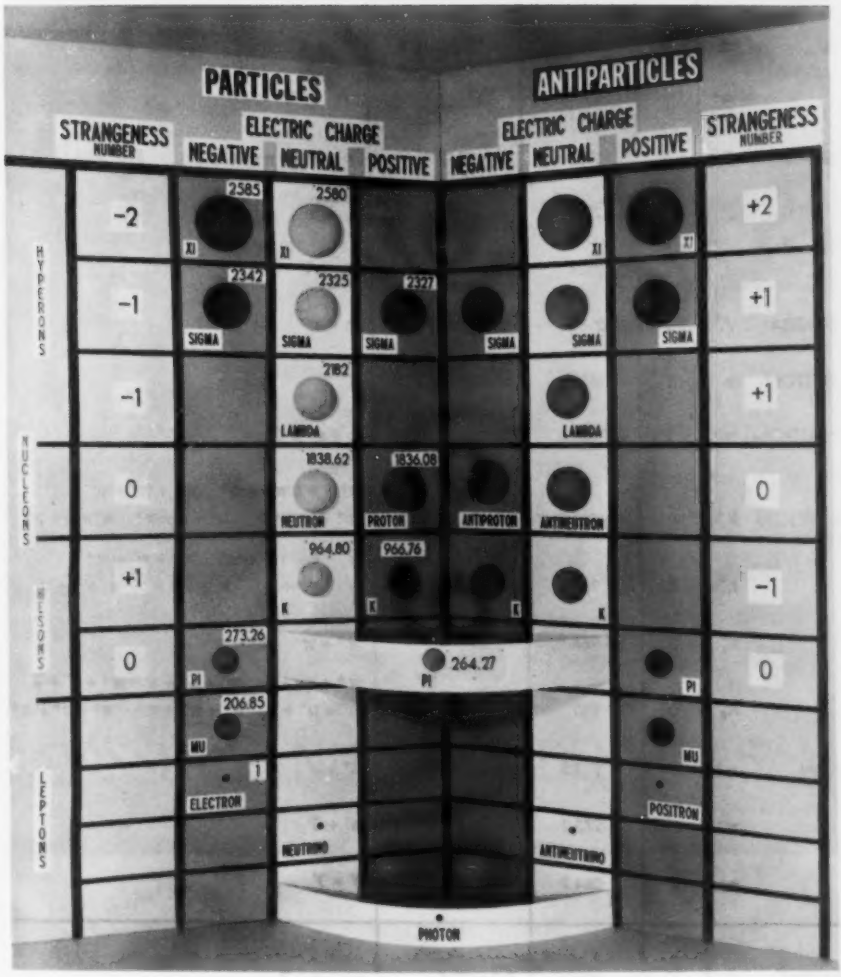
of interest. Indeed, it would be startling should this case be otherwise. Such possibilities are among the most important reasons for taking such a significant step into the unknown.

To recapitulate, the proposed accelerator will:

1. Provide a greatly enhanced source of anti-nucleons and strange particles and hence permit broad extensions of secondary reaction studies;
2. Permit much more extensive and accurate studies of electromagnetic particle production processes;
3. Make possible far more accurate and detailed studies of nucleon structure and the extension of such studies to other particles;
4. Extend to much shorter distances our knowledge of the laws of electromagnetism and possibly disclose anomalies of profound significance;
5. Afford the possibility of opening up as yet unvisualized fields of scientific interest.

In summary, those of us who have so enthusiastically endorsed this proposal have done so because this Linac is the best and indeed the only means to fill a vital need for sharply focussed electron beams of higher energies and far higher intensities than otherwise available; because with minor interruptions in its use and modest capital outlay its energy can be increased to even higher values; and finally and importantly because Professor Panofsky, Professor Hofstadter, Professor Ginzton and their colleagues constitute a group of research physicists and accelerator engineers that is unexcelled in general and is unequalled in the construction and utilization of linear accelerators.


PARTICLES
ANTIPARTICLES
STRANGENESS NUMBER
ELECTRIC CHARGE
NEGATIVE
NEUTRAL
POSITIVE
HYPERONS
NUCLEONS
MESONS
LEPTONS
-2
-1
-1
0
+1
0
+2
+1
+1
0
-1
0
2585
XI
2580
XI
XI
XI
2342
SIGMA
2325
SIGMA
2327
SIGMA
SIGMA
SIGMA
SIGMA
2182
LAMBDA
LAMBDA
1838.62
NEUTRON
1836.08
PROTON
ANTIPROTON
ANTINEUTRON
964.80
K
966.76
K
K
K
273.26
PI
264.27
PI
PI
PI
206.85
MU
MU
1
ELECTRON
POSITRON
NEUTRINO
ANTINEUTRINO
PHOTON

PARTICLE		SPIN	REST MASS (ELECTRON MASSES)	MEAN LIFE (SECONDS)	DECAY PRODUCTS
XI	Ξ^-	$\frac{1}{2}$	2585	10^{-10} TO 10^{-9}	$\Lambda^\circ + \pi^-$
	Ξ°	$\frac{1}{2}$	2570	10^{-10}	$\Lambda^\circ + \pi^\circ$
SIGMA	Σ^+	$\frac{1}{2}$	2325	$.7 \times 10^{-10}$	$p + \pi^\circ \quad n + \pi^+$
	Σ^-	$\frac{1}{2}$	2341	1.5×10^{-10}	$n + \pi^-$
	Σ°	$\frac{1}{2}$	2324	NOT MEASURED	$\Lambda^\circ + \gamma$
LAMBDA	Λ°	$\frac{1}{2}$	2182	2.7×10^{-10}	$p + \pi^- \quad n + \pi^\circ$
PROTON	p	$\frac{1}{2}$	1836.1	STABLE	
NEUTRON	n	$\frac{1}{2}$	1838.6	ABOUT 1,000	$p + e^- + \bar{\nu}$
K MESON	K^+	0	966.5	1.2×10^{-8}	$\mu^+ + \nu \quad \pi^+ + \pi^\circ \quad \pi^+ + \pi^+ + \pi^-$ $\pi^+ + \pi^\circ + \pi^\circ \quad \mu^+ + \nu + \pi^\circ \quad e^+ + \nu + \pi^\circ$
	K^-	0	966.5	1.2×10^{-8}	$\mu^- + \bar{\nu} \quad \pi^- + \pi^\circ \quad \pi^- + \pi^- + \pi^+$ $\pi^- + \pi^\circ + \pi^\circ \quad \mu^- + \bar{\nu} + \pi^\circ \quad e^- + \bar{\nu} + \pi^\circ$
	K_1°	0	965	1×10^{-10}	$\pi^+ + \pi^- \quad \pi^\circ + \pi^\circ$
	K_2°	0	965	3×10^{-8} TO 10^{-4}	$\pi^+ + e^- + \bar{\nu} \quad \pi^- + e^+ + \nu \quad \pi^+ + \mu^- + \bar{\nu}$ $\pi^- + \mu^+ + \nu \quad \pi^+ + \pi^- + \pi^\circ \quad \pi^\circ + \pi^\circ + \pi^\circ$
PION	π^+	0	273.2	2.6×10^{-8}	$\mu^+ + \nu$
	π^-	0	273.2	2.6×10^{-8}	$\mu^- + \bar{\nu}$
	π°	0	264.2	10^{-14} TO 10^{-13}	$\gamma + \gamma$
MUON	μ^-	$\frac{1}{2}$	206.7	2.2×10^{-6}	$e^- + \nu + \bar{\nu}$
ELECTRON	e^-	$\frac{1}{2}$	1	STABLE	
NEUTRINO	ν	$\frac{1}{2}$	0	STABLE	
PHOTON	γ	1	0	STABLE	

Table II

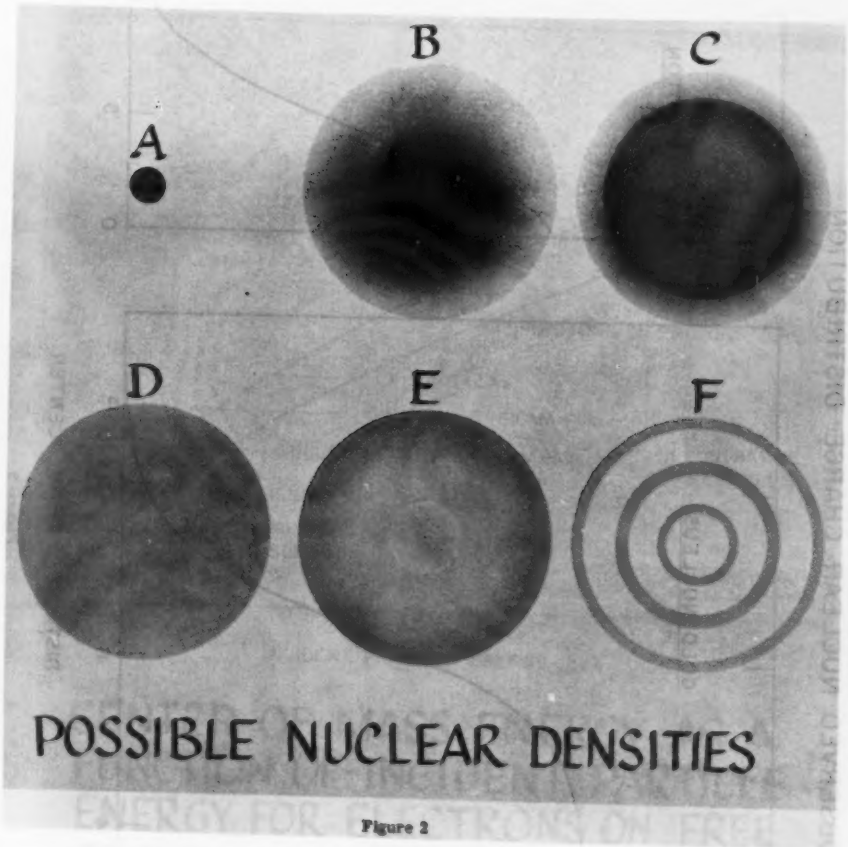


Figure 2

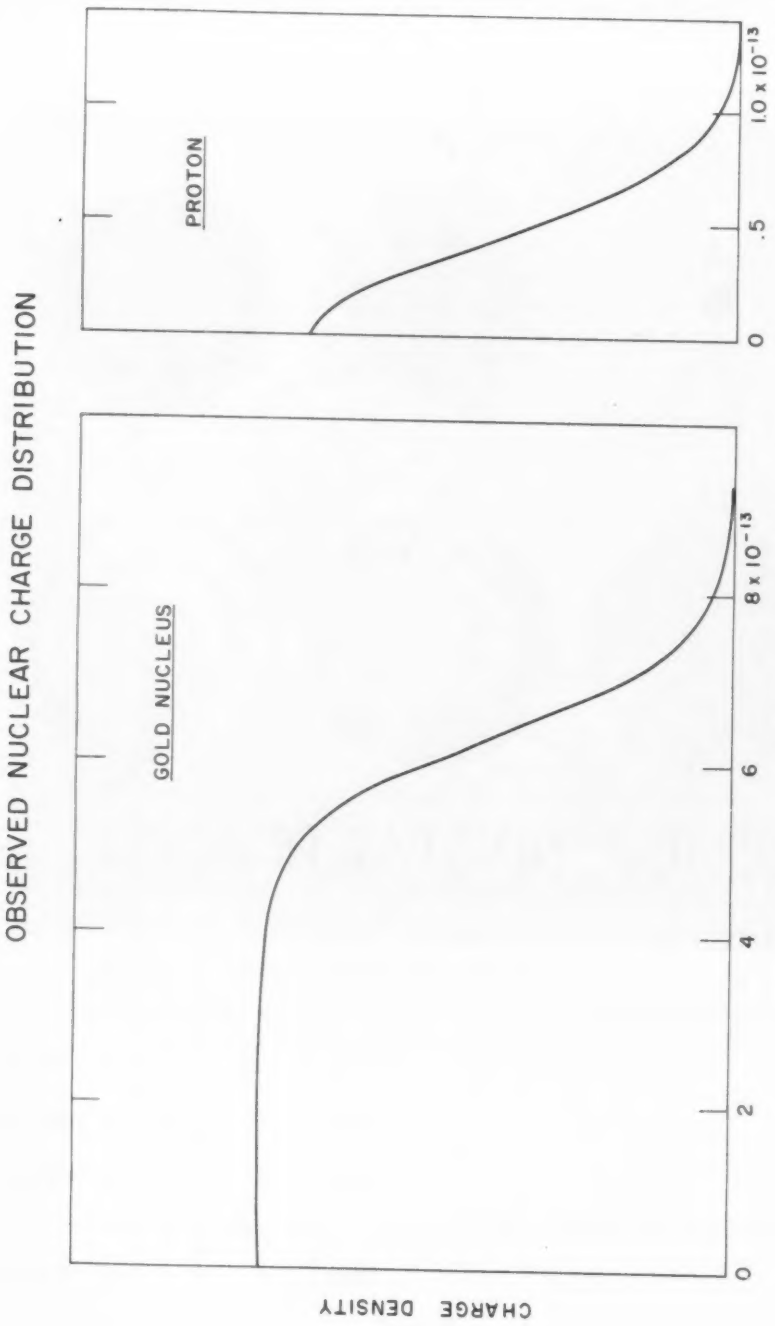
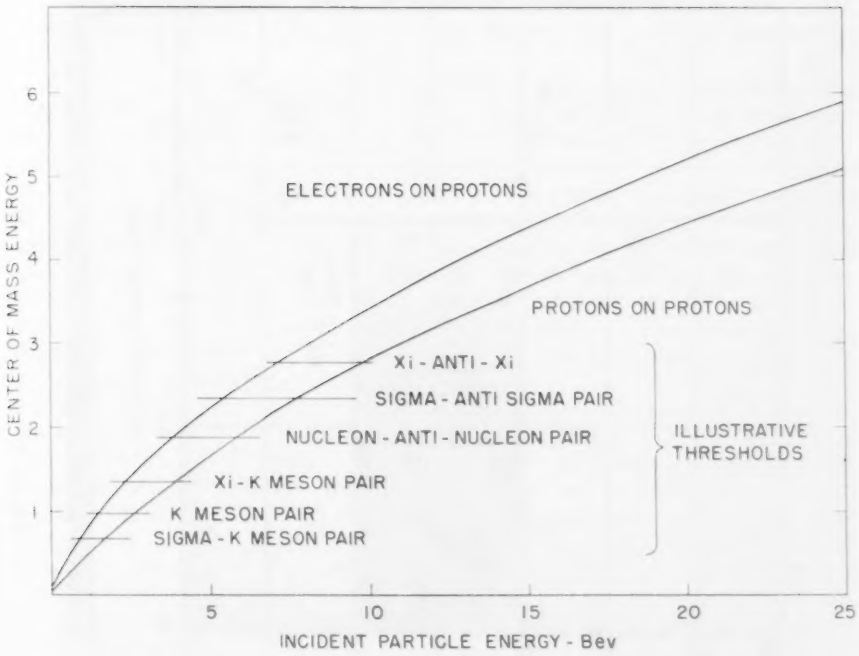

OBSERVED NUCLEAR CHARGE DISTRIBUTION
PROTON
GOLD NUCLEUS
CHARGE DENSITY
0
.5
1.0 x 10⁻¹³
2
4
6
8 x 10⁻¹³
DISTANCE FROM CENTER

Figure 3



CENTER OF MASS ENERGY AS A FUNCTION OF INCIDENT PARTICLE ENERGY FOR ELECTRONS ON FREE PROTONS AND PROTONS ON FREE PROTONS

Figure 4

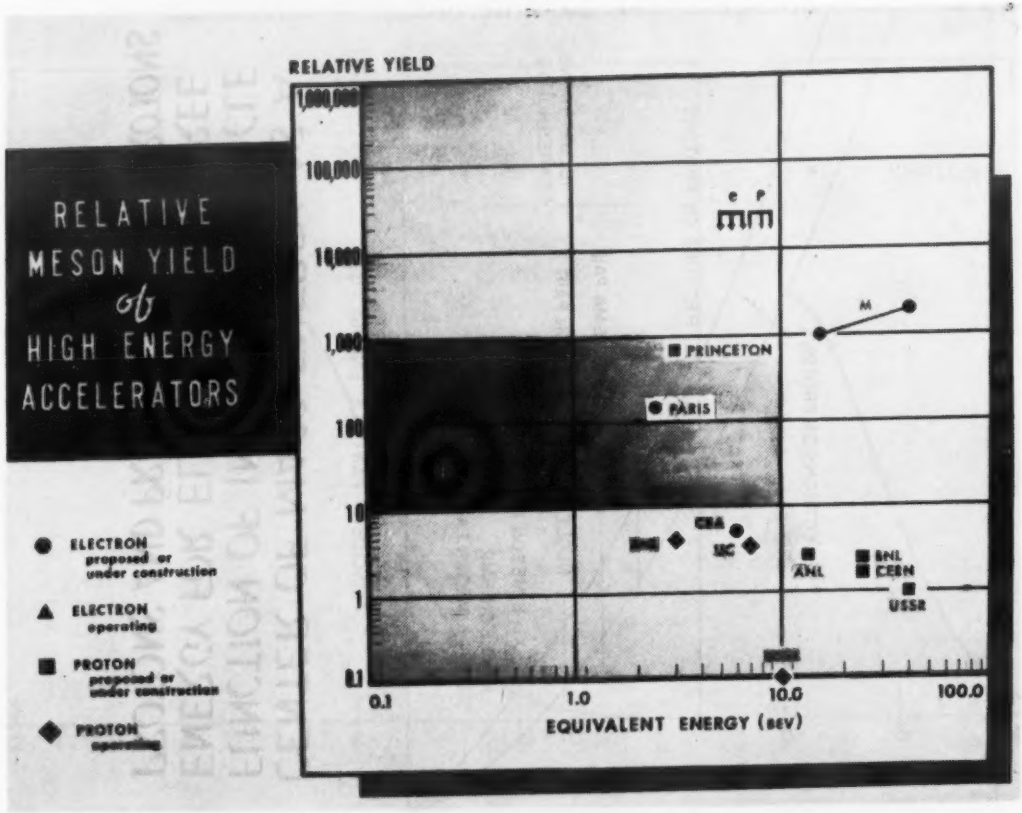

RELATIVE MESON YIELD of HIGH ENERGY ACCELERATORS
RELATIVE YIELD
100,000
10,000
1,000
100
10
1
0.1
e P
M
PRINCETON
PARIS
CEA
BNL
ANL
CERN
USSR
0.1
1.0
10.0
100.0
EQUIVALENT ENERGY (bev)
ELECTRON proposed or under construction
ELECTRON operating
PROTON proposed or under construction
PROTON operating

Figure 5

Dr. HAWORTH. As you are quite aware, the search for basic understanding of the atomic nucleus and of its particles and its internal forces lies at the frontier of modern science. As is well said in the statement of fundamental principles alluded to by Dr. Williams, scientific frontiers are always moving. At present the most basic lie at opposite extremes—in the indefinitely large and in the submicropically small. It is with the latter that we are concerned today.

Man's everlasting search to understand the universe around him began with gross phenomena—with things that he could see and hear and feel and smell. In the next step he devised instruments to measure length and time and mass, and thence force and energy and other quantities—still dealing with matter in the gross. As time went on, he recognized that there must be a finer structure. With microscopes and other tools, he could observe details beyond the power of his senses used directly. He began to search for some underlying pattern. Instinctively, he felt that the vast complexities with which he was surrounded could be explained in terms of various combinations of fairly simple building blocks. There has been a constant search to find and understand those fundamental blocks.

Until fairly recent times the recognizably different substances—water, air, salt, various minerals, and so on—were thought to be the fundamental constituents of matter. Further investigation showed that the almost infinite varieties of molecular substances are compounded from less than one hundred kinds of elementary atoms. The recognition of this elementary structure and the identification of most elements was one of the great scientific triumphs of the 19th century.

Figure 5

Still further study showed that the atoms in turn possess an inner structure. Brilliant research culminating in that of Bohr and Rutherford showed each atom to be a tiny positively charged nucleus carrying nearly all the mass surrounded by one or more electrons whose number characterizes the individual element and determines its chemical and many other properties. The regularity of nuclear progression, the phenomena of natural radioactivity, and later the studies of cosmic rays showed that even now the ultimate had not been reached, that the nucleus itself must have a structure, that still more fundamental particles must be contained therein. The study of the nucleus, begun in earnest only a few decades ago, quickly showed these particles to be protons and neutrons bound together in various combinations by enormous, attractive forces. A major effort in the intervening period has been to dissect the nucleus to determine the nature of the forces, the various energy combinations and the detailed structure. In the process, it began to be apparent that the end had not been reached, that the nucleons themselves, the proton and the neutron. also have a structure and that associated with them in transient form are many other particles. Thus as problems have been solved and questions answered, new questions have arisen. It is toward answering these questions that ultra high energy physics is directed.

Now I will depart from my written statement and talk extemporaneously, if I may, from charts, and so forth.

You are all familiar, of course, with the basic structure I spoke of before, of the nucleus with its protons and neutrons and electrons going around it. We have known for quite a while that there are

involved in this several types of forces between particles. In the first place, there obviously is a very, very strong force inside the nucleus—the nuclear force, or strong force, as it is usually called by the physicists.

Secondly, you know, of course, that there are forces involved between electric charges. Negative and positive charges attract each other and like charges repel. Those forces hold the externals of the atom together and keep the electrons bound to the nucleus to make an atom out of it. To give you an idea of the magnitude of these forces, if we assign the value of one to the nuclear force then the value of an electromagnetic force between two charges at the same distance is only one one-hundredth. So the electric forces are much weaker than the strong forces. There is a third force, which the physicists call the weak force, which is the one that is responsible for radioactive decay, for the emission of gamma rays and electrons and so forth in radioactivity, and that is far, far weaker still. Its strength is only about 10 to the minus fourteenth (10^{-14}) of that of the strong forces. That is, it is about one hundred-thousandth of a trillion of the strong forces. Thus, there are these three basic forces that play the roles in nuclear phenomena.

Just for completeness I will mention that there is a fourth known basic force in the universe, namely, the force of gravitation. It is about 10 to the minus 38, that is, 1 over 10 with 37 zeroes after it, as strong as the strong forces. Obviously it can't play much of a role in the nucleus. The only reason it seems to be a strong force, as we think of it, is because there are so many, many, many particles involved and their effects add up. These forces are the things that make the particles behave as they do, both in terms of the way they act with respect to the outside world and the way they act with respect to the internals of themselves.

I would now like to go to a little discussion of the situation with respect to particles. I borrowed this chart (fig. 1, see p. 79) from my very good friends at the Argonne Laboratory who built it. It is a display of all the elementary particles that have been observed and have been predicted. I think you can see it is a fairly large number. On it you will find particles that you are familiar with. Here is the electron down here. We give it in our units a mass of one. That is, we just arbitrarily give the electron a mass of one and measure everything else in terms of it. It is a very small particle both in mass and size. It has a charge that we call one. We call it a negative charge for historical reasons. Thus, the electron forms the basis of our system of units. Let us turn now to the internals of the nucleus, the ones that you are familiar with. Here is the proton. On the same scale it has a mass of 1836. It is that many times as heavy as an electron. It has a charge, however, of the same value except it is a positive charge instead of a negative charge so they attract each other. Also, within the nucleus are neutrons which have a mass just slightly heavier than the proton and no charge at all. Within the nucleus these are both stable particles, they last forever within the nucleus as long as it is not disturbed.

The proton is stable no matter where it is. If a neutron escapes from the nucleus it is unstable and lives about 12 minutes on the average. There is one other particle you are familiar with although you

may not think of it as a particle. It is the photon. The photon is simply electromagnetic radiation. It is one of the curious aspects of our laws of nature, that particles and waves are different manifestations of the same thing. They are schizophrenic, is the way I like to say it. Sometimes they behave like particles, sometimes like waves. When they behave like waves they have a frequency; when they behave like particles they are more like little pellets, and so forth.

The photon is the electromagnetic wave. All light is made up of photons. Radio waves are in principal made of photons, gamma rays are photons, X-rays are photons, and so forth. So you are entirely familiar with them in that kind of sense. The photon plays a very important role in the following way. It is the thing that makes electric forces exist. Actually the force between charged particles is because photons jump back and forth between them. So it is terribly important with respect to electromagnetic forces.

It was predicted by the Japanese physicist, Yukawa, that nuclear forces must have something of the same sort of thing. He predicted in 1935 that there must be a particle that he called the mesotron, which jumps back and forth between neutrons and protons and causes strong forces.

Twelve years later, the meson, as it was called in shortened form, was discovered. Here it is, the pi meson. It plays the same role in nuclear forces that photons do in electric forces. Thus, we have a fairly simple model, with electrons on the outside, the neutrons and protons held together in the nucleus by the pi meson and electrons held to the nucleus by the photons. It is a pretty picture.

Unfortunately, artists got to work and put a lot of additional things in the picture that complicated it. By a series of theoretical and experimental investigations we have found that there are necessarily four kinds of particles. There are the nucleons, the pi mesons, the leptons (electrons, neutrons, etc.), and the photon, but there are a whole lot more. There are the antiparticles on this end of the chart. These particles are ones, the properties of which I cannot really explain to you. It is almost metaphysical. They are mirror images of the particles with which we are familiar.

Here is the antielectron or the positron. It has a positive charge rather than a negative charge. If the positron and electron get together they mutually annihilate each other. There are no particles left. Instead energy is given off in the form of photons and goes off as very hard gamma rays. Similarly, there is an antipimeson. It has the opposite charge; it is plus instead of minus. They can get together and annihilate. There is an antiproton which has a negative rather than a positive charge. There is an antineutron. All corresponding pairs can annihilate. You will remember that the bevatron at Berkeley found these in 1955.

Representative PRICE. We have worked on the ANP program for years so I am familiar with the antiparticles.

Dr. HAWORTH. We have our four kinds of particles and we have our antiparticles. Then in about 1950 there was an avalanche. The roof fell in. First it was observed that there were some other mesons which were called K mesons, which were heavier than the pi mesons. It was observed that there were some other heavier particles, heavier than the neutron and the proton that could be made from them if you

did the right thing. These particles have very strange properties. They live a million trillion times, in round numbers, as long as they should. That is, some of them do. It is a very complicated business. They have a property called strangeness. The strangeness must be conserved. You must make one with negative strangeness at the same time as you make one with the positive strangeness, so the total strangeness is zero and so forth. Spins must be conserved, energy must be conserved, ad infinitum.

So there are on this chart 31 particles of which 22 have actually been observed. This group up here has not been observed because we don't have enough energy in our accelerators to make them. We know perfectly well they are there but nobody has found them.

It is just a very confused situation. We know, or our instinct tells us, that it is not really that complicated. Behind this there must be simpler things. These are complicated manifestations of simpler laws that we have not found yet. Now if we can turn to other charts, this (fig. 4, p. 83) illustrates the thing I said a moment ago about our energies. This is a plot of energy where this curve applies to protons and this to electrons. These lines across here represent how much energy in the so-called center of mass system one has to have to make these various particles. So if you want to see how much it would take to make an antiproton—I am sorry—to make an antiproton or an antineutron—and incidentally you have to make them with their cousins, you cannot make one at a time—then you can look down here and see how high the energy has to be. If you do look down here you will see it is just about 6 Bev., which is the energy of the bevatron, and the bevatron was designed to be 6 Bev. precisely so it could make this particle which had been predicted but never discovered.

If you look up here to some of the higher ones you find that it would take 10 Bev. protons to make the top particles there. With electrons, fortunately, it is somewhat less. It is more like 7 Bev. to make a pair of these particles. So it goes. When we get upon into this region of 6, 8, 10 Bev., we are in the top of the region that we have to be in to make all these various particles.

Another thing of interest in addition to what are the particles is how many of them there are, how do you make them, what is the shape, the size, the density, the structure of these particles. Just for fun I have illustrated on here (fig. 2, p. 81) various things that they might be. They might be a little point. They might be a solid sphere. They might have a little core like the peach. They might be fairly solid with a tapering off edge and so forth. I point this out because this type of study is one of the very most, if not the very most, important uses for high energy electrons as distinguished from protons.

That is for two reasons. In the first place, we know a lot about the interaction of electromagnetic forces. When you use electrons and bombard a nucleus, the forces are electric and magnetic forces, not nuclear forces. So we can understand a lot better the observations that we make if we use electrons.

In the second place, because those forces are considerably weaker than the nuclear forces, the electron has a chance to penetrate the nucleus. If you bombard one nucleon with another, the forces are

so strong that you don't get a study of the structure. You may get some damage. So for two reasons the electrons are much the best. In order to examine details, you have to have very short wavelengths. Going back you remember I said particles act like waves—the wavelength of the particles being inversely proportional to the energy. The more the energy the shorter the wavelength. I think if you visualize waves on water, that you would not expect a long ocean wave to be able to tell you much about the internal structure of a starfish. You would want little ripples and so forth to study such fine details. So you want short wavelengths. Short wavelengths require high energy and the higher the energy the shorter the wavelength. Therefore, to get down to the internals of these particles we must have very short wave lengths. They are now short enough so that we have been able to make a few observations.

In the first place it has been found that a nucleus, a heavy nucleus, has a structure much like this (model C, fig. 2, p. 81) a constant density to near the edge and then it tapers off. This tapering off is more or less constant for all nuclei. As you go to lighter and lighter nuclei the central core shrinks and gets smaller and smaller until you get down to where there is not a solid center. This blackened part is just proportional to the number of particles in the nucleus as we may naively expect.

We have not been able to find out if there is a shell-like structure such as there is in the external atom. We found that a proton or neutron has a shape that is simply dense in the center and falls off. It starts decreasing from the center but it is much smaller than the nucleus. This has been done with the existing Stanford accelerator, the 700 Mev accelerator. I would like to remark that even though the Stanford work had made no contribution whatever toward the accelerator we are talking about today, it has still been tremendously significant. The money that has gone into the Mark III accelerator has been well worthwhile for research.

Summarizing this brief description, we see that we are confronted with a bewildering situation. Twenty-two elementary particles have been observed and nine additional ones have been predicted. With a few exceptions, we know discouragingly little about them. To be sure we know their charge, their spin, their mass, their strangeness. We know something of the circumstances in which the transient ones can be produced and in what numbers. We know something of their interactions with other particles but there are enormous gaps. We have little knowledge of their internal structure.

There are innumerable unsolved problems. The structures and properties of the various particles must be much better known. We must have far better understanding of the interacting forces. We must search for new and unexpected particles and new phenomena. The list is almost endless.

Our knowledge can be effectively increased only through the use of ultra-high energy accelerators of diverse capabilities. The spectacular increase in proton accelerator energies in recent times has somewhat obscured the fact that many other parameters are also quite important.

We must have electrons as well as protons; we must have intensities great enough to permit rapid observation of the various direct

processes and to produce copious quantities of all transient elementary particles for use in secondary interaction studies; we must have sharply focused beams and flexibility in time and space to suit the various purposes.

Representative PRICE. Doctor, in the middle of the paragraph, would you describe what the intensities are?

Dr. HAWORTH. My last chart will show that, Mr. Price.

There is an especially acute need for very high energy electrons in large intensities and in well-focused beams. Because of easier and cheaper adaptation to circular machines, protons have been produced at energies far above those available with electrons.

Dr. Williams told you something about that this morning when he drew the circle on the blackboard and the energy loss as the electrons move in a circle. That loss does not occur in any significant amount with protons. It occurs only with electrons. That is why protons can be used in circular machines much more effectively.

In contrast to the proton case where 6 Bev. has been available and 30 will soon be reached, electron energies have so far been limited to 1 Bev. An important step that will fill an urgent need is being taken by construction of the 6 Bev. Cambridge electron accelerator (CEA), which will be research use in a couple of years. However, important though its potential contributions, there will be a vital need for higher currents, and much more sharply focused beams than it will be able to provide. The linear accelerator proposed will effectively meet these requirements. In its initial form it will have twice the energy and some 50 to 100 times the intensity of the CEA. (See fig. 5, p. 84.) This is a chart which is like the one Dr. Williams used but which has one important modification. Here I am measuring not the current but the effective number of particles that will be produced by the accelerator because it is somewhat different per electron than it is per proton. It is slightly less. In fact, it is substantially less for electrons than protons. I have taken that debit already into consideration on this chart. In other words, the electron values have been lowered compared to the proton values from that standpoint.

As in all linear accelerators and in contrast to the circular machines, a full strength sharply focused beam will emerge into free laboratory space where it will be quite accessible and can be used in many different ways.

Remember in the circular machine the beam is inside the machine. You can get a fraction of it out but it tends to spray out and not be well focused and so forth.

As time goes on and need arises, the energy can be increased to as much as 45 Bev., both by increases in the power of the individual klystrons, and that will inevitably happen without additional capital installations, and by adding klystrons at relatively modest cost. By virtue of this flexibility, it can belong to more than one generation of machines.

Let us now examine some of the more specific applications for this accelerator. In the first place, it will be a far more copious source of all these new secondary, strange, and so forth particles, than any in the present program, which is confined to lower intensity pulsed circular machines. Here we might examine figure 5 (p. 84) for a moment. This is a logarithmic scale. Each major line is a factor

of 10, so here we have 1, 2, 3, 4, and 5 Bev. The bevatron is at 6; the CEA is at 6. These are actually practically on top of each other. Below the thresholds required to make this group of particles here. The CEA will be right in the middle. It will certainly make some. It may make all.

It is a little bit on the ragged edge. In terms of those particles in the upper right-hand corner, to be really safe you need to get up in here somewhere, not quite as far with electrons as with protons. When we look at the energy range here, we can see how far superior this linear accelerator is to the other machines in terms of numbers of particles.

I want to be careful. That doesn't mean that a machine out in here isn't all right. It is extremely useful. These machines are 25 to 30 Bev., where this is 10, 12, or 15, or whatever it works out to be. So there may be phenomena that will be observed by these that are not observed at all by this. But the ones that they can both do, this one will do far more copiously. Even though electrons, and the photons they produce, are less efficient than are protons as producers of most particles, the Linac will still far excel. The higher energies and intensities to be available make possible significant extensions of secondary interaction studies. That is where we use these particles in turn as projectiles to bombard nuclei and study interactions.

This is true especially with particles, which are otherwise too rare to be so used. Of the particles we have observed we don't have enough to do any more than to just look at them.

But the primary scientific interest in this machine lies in studying directly the specifics of electromagnetic interactions. The production of secondary particles is by a different mechanism than with protons and one that seems simpler because we have a better understanding of electromagnetic than of nuclear forces. The production of all known strange particles by the electromagnetic interaction at energies well above their thresholds should yield extremely valuable information concerning the production processes. It is also possible that new and as yet unknown particles will be produced.

Especially interesting is the possibility of the direct electromagnetic production of weakly interacting particles not hitherto observed. The very high intensities expected are essential to any search for such inevitably rare events. The implication of this is that there may be down toward the bottom of the chart new particles that we don't know about, that we have enough energy to make but we have never had enough intensity to make enough to see them. Intensity is terribly important as well as the energy of individual particles.

The unique potentiality of the proposed accelerator lies, however, in the possibilities it affords for structural studies of elementary particles. A 12 Bev. electron striking a proton has a wavelength only about one-sixth that of the highest energy electrons used so far. Indeed, this wavelength is only about one-twentieth of the radius of the proton and the proton structure could in principle be studied to features of this size.

We could probe into the depth of the proton to see if it has an internal structure rather than the fuzzed sort of thing. The structure studies can be of two general sorts. Elastic scattering experiments can extend those described earlier to give more detailed information on the structure of the nucleus and of the proton and the neu-

tron. In inelastic interactions where secondaries are produced, information can be gathered as to the structure of both the struck and of the secondary particle. This will be a tremendous asset because so far we have not been able to study the structure of these transient particles at all.

Perhaps most important of all the possibilities is a very general consideration. Inherent in all the experiments described, and in others conducted for the purpose, is the study of the electromagnetic interaction itself. It is quite possible that at the very short distances involved the laws of quantum electrodynamics may be altered or even fail completely.

Indeed the results of such experiments could raise questions of great philosophic and scientific interest. Under certain circumstances, the question might be raised of a radical revision of our concept of space itself. At sufficiently short distances do the axioms of Euclidean geometry fail? Can even the notion of continuity of space itself be maintained? Even should such conceivable anomalies not be found, information on these points would be most valuable.

In addition, it should, of course, be pointed out that in all previous experience such significant extensions in experimental possibilities, as here proposed, have led to completely unanticipated results and opened new realms of interest. Indeed, it would be startling should this case be otherwise. Such possibilities are among the most important reasons for taking such a significant step into the unknown.

To recapitulate, the proposed accelerator will:

1. Provide a greatly enhanced source of antinucleons and strange particles and hence permit broad extensions of secondary reaction studies.

2. Permit much more extensive and accurate studies of electromagnetic particle production processes.

3. Make possible far more accurate and detailed studies of nucleon structure and the extension of such studies to other particles.

4. Extend to much shorter distances our knowledge of the laws of electromagnetism and possibly disclose anomalies of profound significance.

5. Afford the possibility of opening up as yet unvisualized fields of scientific interest.

In summary, those of us who have so enthusiastically endorsed this proposal have done so because this Linac is the best and indeed the only means to fill a vital need for sharply focused electron beams of higher energies and far higher intensities than otherwise available; because with minor interruptions in its use and modest capital outlay its energy can be increased to even higher values; and finally and importantly because Professor Panofsky, Professor Hofstadter, Professor Ginzton and their colleagues constitute a group of research physicists and accelerator engineers that is unexcelled in general and is unequaled in the construction and utilization of linear accelerators.

Thank you very much.

Representative PRICE. Are there any questions?

Senator BENNETT. We had one question come up yesterday. Is there a meeting in London to discuss "few nucleons"?

Dr. WILLIAMS. I just returned from that conference Sunday afternoon.

Chairman ANDERSON. In four or five well chosen words, what is a "few nucleons"?

Dr. WILLIAMS. The fewest is two. The few nucleon problem is what happens when one nucleon strikes another and by this collision and scattering one can find out the details of the law of force exerted in between. If you do that, then there would be hope that if you have three together, knowing the interaction of any two, you can describe how three behave. What a triton might be. This is the problem to try to describe the behavior of the nucleus in terms of the interaction of pairs of nucleons that exist.

Senator BENNETT. Mr. Chairman, it is very comforting to note that the meeting has been held and we don't have to go into it.

Representative PRICE. Dr. Haworth, you were on the President's Panel that looked into this proposal. Are you satisfied it was very thoroughly looked into?

Dr. HAWORTH. Yes, Mr. Price. As a matter of fact, I was on both panels, as you probably know. Between them a number of us spent a very substantial fraction of our time for a good many months looking into this whole question. We did not look just at the Stanford accelerator, but at the total picture.

Representative PRICE. What other panel are you referring to?

Dr. HAWORTH. The National Science Foundation Panel on High Energy Accelerators, which preceded the President's panel. This is a panel of 12 people, I believe, all of them from laboratories active in this field. We spent a great deal of time looking at this total question, and I believe everyone did a very thorough job.

Representative PRICE. On the two panels that you referred to, and any other panel you may have considered the Stanford accelerator, do you feel that there was appropriate representation of the various proponents of other types of accelerators and from various regions?

Dr. HAWORTH. Sir, I would like to read to you the list that has on the National Science Foundation panel in addition to myself. Dr. Herbert Anderson of the University of Chicago. Of course, the University of Chicago people will be big users of the Argonne accelerator.

Dr. Richard Crane of the University of Michigan, who is president of MURA.

Dr. Bernard Feld from MIT, who will be one of the most distinguished users of the Cambridge accelerator.

Dr. Ed Lofgren from Berkeley, who is in charge of the bevatron.

Dr. Schiff from Stanford.

Dr. Frederick Seitz, whom many know, who is chairman of the physics department at the University of Illinois. They also will be big users at Argonne, and they are members of MURA.

Dr. Robert Serber, of Columbia University, who is one of the outstanding theoretical people both in the research use of these machines and also in the design of machines themselves. He was one of two people that helped develop the original betatron which started off these very high energy machines. He was a colleague of mine at Illinois at that time.

Mr. Milton G. White, who is the head of the accelerator project at Princeton University.

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Dr. R. Wilson, or Cornell University, who is in charge of the 1.4 Bev. electron machine there. And finally myself.

On the other panel there was McMillan, who is the director of the Lawrence Radiation Laboratory at Berkeley; Dr. Piore, who has already been mentioned; Dr. Hans Bethe from Cornell, who is one of the outstanding theoretical men in the world in this field; Dr. Jesse Beams, from the University of Virginia, and myself. So the different groups were very well represented.

Chairman ANDERSON. Doctor, I had some communication a while ago from people who were interested in the MURA project. This person said that the MURA project got turned down in the United States, but our exposition of it was sufficiently good so that Russia is starting to build one. Have you heard anything to that effect?

Dr. HAWORTH. I have not heard that; no.

Chairman ANDERSON. Do you know the basis of the new large Russian one?

Dr. HAWORTH. The new large Russian one, to the best of my knowledge, is a larger version of the Brookhaven alternating gradient synchrotron, a 50-Bev. machine of roughly twice the diameter.

Representative PRICE. In other words, it is a stepped-up version of the one they presently have?

Dr. HAWORTH. If I can go back to the chart (fig. 5, p. 84) the one that we usually speak of as their having is this one down here, 10 Bev. That is simply a Chinese copy, but on a bigger scale, of the bevatron. If you take a photograph of it and put it alongside of the photograph of the bevatron and make the one picture twice as big as the other, you would never know the difference. It is not working very well. Its intensity is low, and there are fairly fundamental engineering difficulties that they are having trouble with. It is not shown on this chart, but they are building one right in here, which is actually a smaller version of the Brookhaven AGS. They are building it as a model for this 50 Bev. one which we put on this chart. You must realize, of course, that intensitywise the Russian one is just speculation. We don't know. They don't know, either. We can make pretty good estimates on those that are engineered and so forth. The say it is going to be 50 Bev. Where it belongs up and down we don't know. We know it can't be very high. But whether it will be here, here, or here, we don't know. We gave them the benefit of the doubt on this chart.

Representative VAN ZANDT. Regarding the 10 Bev., is it the Dubna facility?

Dr. HAWORTH. Yes.

Representative VAN ZANDT. You say they are still having trouble?

Dr. HAWORTH. My best secondhand information was in April and they were still way down here.

Representative VAN ZANDT. We were there in the fall of 1957 and they were having trouble then.

Dr. HAWORTH. Yes. You might be interested as far as we can tell what their major difficulty is. There are 36,000 tons of steel in that machine. Obviously they didn't pour it out of one ladle in the steel mill. As you take different batches they will be of different quality. In the cosmotron and bevatron and all these other machines we very carefully measured each block of the magnet, and then we placed them

in position so that a good one is next to a bad one, so then it averages out around the machine. They took them in order as they came from the mill. So they have one side of the machine that is different from the other in terms of the quality of the steel and so forth. That is basically what is causing the trouble.

Representative PRICE. Is this speculation?

Dr. HAWORTH. No, we know that to be so. They admit that.

Representative PRICE. Are there any further questions?

Chairman ANDERSON. Before we finish, Mr. McCone, before you came in, I raised the question of these electrical current costs here, and in the Northwest, because there was some suggestion of the use of a tunnel in the Northwest. The Senate Interior Committee has had before it this problem of an intertie between the Northwest grid and an application that Pacific Gas & Electric has made to bring some of that current down to California. I don't believe they are going to use more than 60,000 kilowatts even in that intertie. I am wondering why if the intertie is going to be built that the Government does not bring it right down and supply it to this project. Each mill will save you many dollars a year, roughly, so that a difference of 3 mills in cost might save $3 million a year.

Mr. MCCONE. A mill would save you $420,000 a year. It is about $7 a kilowatt year per mill, if my arithmetic is right.

Chairman ANDERSON. I will take that figure. Mine was a very big guess.

Mr. MCCONE. That is at an 80 percent load factor. That would be about $7; 60,000 kilowatts would be about $420,000 a year per mill. I don't know what the transportation cost of that power would be. We can go into this pretty carefully. We have not done it.

Chairman ANDERSON. I am only suggesting that if the intertie is being arranged for the benefit of taking care of some of the States, it would be terrible to sell it at 2 mills and buy it at the other end at 6 or more.

Mr. MCCONE. Yes. There are very complicated arrangements as to how that low-cost Bonneville power comes in.

Chairman ANDERSON. They are planning to buy it at dump power rates which is away below 2 mills. I only suggest that might be explored.

(Correspondence on this matter follows:)

JULY 21, 1959.

Hon. JOHN A. MCCONE,
Atomic Energy Commission,
Washington, D.C.

DEAR MR. MCCONE: This is in reference to our conversation of a few days ago during a joint committee hearing on the linear electron accelerator proposed to be built at Stanford University.

At that time the relative cost of electricity as it might affect the annual operating expense of the accelerator was a topic of discussion.

At its proposed initial power, the accelerator must have available a firm supply of 60,000 kilowatts of electric energy. Should the accelerator be extended to its ultimate 45 billion electron volts, as testimony indicated it might, the demand for power would scale upward in excess of 200,000 kilowatts. Obviously, the cost of electricity in operating the accelerator is of prime importance.

I would be interested to know what thought the Commission—and the administration in general—may have given to this matter, the alternatives which might have been studied, and what efforts could now be made to reduce the prospective cost of electric energy as eventually delivered to the accelerator.

Doubtless you are aware that on April 8 and 9, 1959, hearings were conducted by the Senate Subcommittee on Irrigation and Reclamation on proposals that the Pacific Gas & Electric Co. be allowed to build an intertie between the Bonneville Power Administration service area and California. A report is due by the end of this year as to a final recommendation as to the desirability of this intertie, but there was considerable evidence that it would be beneficial, at least to California. There is surplus electric energy in the Bonneville area during certain months of the year which could be made available by means of the intertie to California, where, during the same months of the year, a power shortage exists.

My thought is that the surplus Bonneville power, generated in a Government-owned facility, could be used to advantage in the operation of another Government-owned facility—the proposed Stanford accelerator. If the intertie were constructed, it could make at least some power available to Stanford at dump rates below the presently quoted rates from private sources. After a preliminary look at the estimated cost of the intertie, it would seem to me that the Government might make accelerator operating savings of such size by means of the intertie that it could pay for constructing the high-voltage intertie transmission lines, not to mention other benefits enumerated in the hearings.

I would be pleased if the Atomic Energy Commission would look into this proposed intertie in an effort to find out two things:

(1) If it is decided to construct the intertie, would it be to the advantage of the Government to revert to the earlier program which was proposed on March 19, 1959, in House Resolution 3294 of the then Congressman Clair Engle, now Senator Clair Engle, by which the Government would build the intertie, since Bonneville power is public power? or

(2) If Pacific Gas & Electric is to build the intertie to wheel its public power into its privately owned distribution lines, should it be required to make a wheeling agreement with the Government that it would move certain amounts of this power to the Stanford accelerator at what obviously should be substantial savings to the Government?

When we had the hearings on the intertie, I was of the opinion that it might be to the advantage of the Government as well as to the utility if this dump power from Bonneville could be all utilized, but at that time I had no knowledge of the Stanford accelerator. It seems to me that the Stanford accelerator makes the intertie far more desirable in that it can give a chance for private industry to have some of the dump power for its own use, but at the same time make the initial block of power transmitted over the intertie available for Government operation of the Stanford accelerator.

Sincerely yours,

CLINTON P. ANDERSON.

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., July 27, 1959.

Hon. CLINTON P. ANDERSON,
Chairman, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR SENATOR ANDERSON: Your letter of July 21 requested information on relative cost of electricity as it might affect the annual operating expense of the proposed linear electron accelerator at Stanford University.

Based on most recent Stanford computations, the accelerator will have initially a connected load of about 50,000 kilovolt-amperes with the possibility of expanding to 120,000 kilovolt-amperes with extension of the machine. The average monthly power demand for the initial machine will be about 30,000 kilovolt-amperes with a load factor of about 60 percent. Stanford estimates full-time utilization of the machine, but the power demand will vary and is expected to average about half the maximum energy. As the accelerator will operate continuously while experiments are being conducted, our studies have been based on using firm power for this load.

It may be possible to develop some savings by using dump power from the Bonneville Power Administration, firmed up by power from other sources. This becomes a very complex problem, however, and the results will depend largely on negotiations and arrangements that can be made for bringing such power to the Stanford site.

As you realize, this project is in the early stages and many of the details have not been fully explored. To date, Stanford's cost estimates have been based on standard rate schedules from the Pacific Gas & Electric Co. These schedules indicate power costs of approximately 9 mills per kilowatt-hour at the anticipated load factor. This figure has been included as one element in the Stanford operating cost estimate. There are indications that these costs can be reduced by negotiations at a later date, when more definitive information regarding the project power demand is available.

We have discussed our requirements with the Bonneville Power Administration and have asked them to consider the problem of serving the accelerator load with low-cost power. As a result of the hearings, referred to in your letter, before the Senate Subcommittee on Irrigation and Reclamation, held on April 8 and 9, 1959, discussions are now in progress among Bonneville, the private utilities, and the numerous other Federal, State, and municipal agencies in the area, which will cover the questions set forth on the second page of your letter. We will work with Bonneville to develop answers to these questions.

We will keep you advised of the results of our review and the cooperative studies with Stanford and the Bonneville Power Administration.

Sincerely yours,

JOHN A. MCCONE, *Chairman.*

(Further correspondence on energy costs will be found in app. 11, p. 644.)

Mr. MCCONE. We will do that.

Representative VAN ZANDT. Dr. Haworth, in your statement you pay a tribute to a group of physicists, especially Dr. Panofsky.

Dr. HAWORTH. Yes.

Representative VAN ZANDT. I might say a few of us were in Geneva a few weeks ago observing Dr. Panofsky in his new role as the head of our technical group and he is doing a magnificent job.

Dr. HAWORTH. I am sure he would. I have known him for a long, long time, and I have never seen him to be anything else but magnificent.

Representative VAN ZANDT. While he appeared to dislike the political flavor of the atmosphere, technically he was doing a terrific job.

Dr. HAWORTH. I am sure.

Representative PRICE. Doctor, this question has been asked before, but for the purpose of the record, I would like to have your comment. That is the fact that the Cambridge 6 Bev. accelerator was considered during your deliberations on the necessity of the Stanford machine?

Dr. HAWORTH. That is right. The NSF Panel and the other panel studied the whole field, all the accelerators, and the uses for them. We did not simply look at the Stanford thing, as an isolated matter. That was our job. As we have every 2 years for several years, we were instructed to look at the whole picture.

Representative PRICE. Notwithstanding the fact that the Cambridge accelerator will come into operation within a year or so, it was thought sufficiently advantageous—to be enough newness about this linear accelerator to make it of importance in the program?

Dr. HAWORTH. That is right. There are three important reasons. One is the energy. If anything, that is probably the least of the three. The really important ones are: first, the very much higher intensity. You can see on that scale it is more than 100; it has 50 to 100 or more times as many particles as the Cambridge accelerator. Second, terribly important for these things that I call structure studies, is the fact that the linear accelerator has a beam coming out at the end which is sharp—which is focused so you can make accurate measurements for studying the internal structures. It is a much more effective machine than any circular machine could possibly be.

Representative PRICE. You have about reached your limitation with the circular machine with the Cambridge accelerator?

Dr. HAWORTH. That is right.

Representative PRICE. Are there any further questions? If not, the next witness will be Dr. Edward L. Ginzton.

Thank you very much, Mr. McCone and Mr. Floberg.

Mr. MCCONE. Thank you, Mr. Chairman.

STATEMENT OF DR. EDWARD L. GINZTON, DIRECTOR, STANFORD MICROWAVE LABORATORY, STANFORD UNIVERSITY

Dr. GINZTON. Mr. Chairman, I would like to offer a prepared written statement which ties together our formal proposals with what has been said before. This written statement is much too long for me to present orally. Therefore, I would like to offer it for the record, if I may.

Representative PRICE. It will be accepted as part of the record.[1]

(The statement referred to follows:)

[1] See app. 5, p. 565, for list of technical reports prepared by Stanford on accelerators.

Appendix 6

THE PROPOSED STANFORD TWO-MILE LINEAR ELECTRON ACCELERATOR

Statement of E. L. Ginzton,
Stanford University, July 14, 1959

SUMMARY

The material presented by Mr. Floberg, Dr. Williams, and Dr. Haworth which precedes this document has amply described the proposed construction of a large linear accelerator at Stanford University. It remains for the representatives of Stanford to give you a description of the project.

The salient features of the proposed accelerator are as follows:

1. It will accelerate electrons rather than protons, which would make it a unique facility among machines above 10 Bev.

2. Under conservative operating conditions it will produce an energy of 15 Bev.

3. It can later be expanded to an energy of 45 Bev at a small fraction of the cost of a new machine at that energy.

4. It will have higher beam intensity by a factor of 10,000 than other proposed machines in the same energy range.

5. The excellent geometrical characteristics of its beam will accentuate its usefulness as a research tool.

Since we are aware that the project would involve the largest single expenditure of funds for a single-purpose research activity, we feel it important to describe not only the ultimate aim of the program but also to give you a simple picture which will show how a linear electron accelerator operates, and how the present two-mile accelerator proposal evolved from a modest beginning in 1947.

The development of the linear electron accelerator at Stanford has occupied a span of many years, starting with Hansen's invention of

the rhumbatron in 1935, and exploiting the Varian invention of the klystron at Stanford in 1937. In the post-war period, ten accelerators have been built at Stanford for various purposes; one of these, the Mark III, has clearly demonstrated the usefulness of the linear accelerator in high-energy particle research; another, the Mark IV, was built to provide a vehicle for research and development of components and to establish a firm basis for any future proposal for a multi-Bev accelerator. The idea of building a very large linear accelerator was first considered seriously by the Stanford group immediately upon the completion of the billion-volt Mark III accelerator. The evolution of particle physics and the continuous interplay of experience with the Mark III and component improvements provided by the Mark IV, together with theoretical studies of various kinds, led to the point where a serious consideration of the technical features of a two-mile accelerator was possible in 1956, resulting in a proposal to the Government in April 1957. Further cost studies, component development, and other related activities have been in constant progress at Stanford up to the present time. Based on this continuing work, we believe that we are now ready for the preparation of final designs, blueprints, and construction.

Construction costs, now estimated at $105,000,000, with a parallel expenditure of $18,000,000 for component development and testing, have been arrived at over a period of three years of study, constant review by Stanford groups, industrial firms, consultants, and personnel in the Atomic Energy Commission. We feel that these estimates are as accurate as they can be made prior to obtaining actual bids from formal blueprints.

The cost of operation, upon completion of construction, is estimated at $15,000,000 per year. This is a reasonable budget, being based upon extrapolation of our present experience with Mark III operation, and taking into account a 24-hour-per-day operations schedule and the experience of many other institutions where large accelerators are now in operation.

We should like to repeat what you have heard stated by others: we propose to make the facility, upon completion, available to qualified scientists without regard to their normal residence. We fully recognize that despite the fact that construction of the proposed two-mile machine can only be carried out by Stanford personnel at the present time, the expenditure of so large a sum of money would necessarily place this activity in the class of a national facility. We propose to assure this arrangement by creating a suitable administrative structure with participation from many universities and other establishments. We would also like to observe that the value of this project lies not only in its being the largest accelerator in the world, but also in the fact that it is basically different from all other high-energy instruments above 10 Bev being built or designed in the United States and elsewhere. Much of the fundamental information about the nuclear world is as yet imperfectly understood, making it impossible to establish a specific research program for any multi-Bev machine far in advance. Because of this, we believe that diversity among several installations - in kind of particle, energy, intensity, geometrical factors, and other beam considerations - is as fundamentally important to final success as is the

size of the machine and its potential energy. Thus, we do not believe that it competes with any existing project but rather is complementary to them.

Finally, we fully recognize that the scope of the project represents a major engineering challenge. We have carefully considered the many possible difficulties, and we firmly believe that the machine will work very successfully and will represent a major asset in the efforts of science to obtain a basic understanding of the structure of matter.

I. INTRODUCTION

It will be my purpose today to describe to you the large linear electron accelerator which has been proposed for construction at Stanford University. Before going into the details of operation of the proposed machine and its characteristics and potential usefulness in nuclear physics research, I should like to describe briefly to you the way in which our proposal came to be, and the various steps it has gone through since it was first formulated.

As early as 1954 there developed an interest at Stanford in exploring the possibility of a multi-Bev linear electron accelerator. The Mark III accelerator, now operating at 700 Mev, had then been in use for about two years. The results with this machine had been sufficiently promising during that time, and its operation so satisfactory, that we began to consider the problems which might arise with a much larger machine. Our preliminary work showed quite clearly that the idea of a much larger machine, perhaps two miles long, was in fact a sound one, since it required the development of no new basic ideas or techniques, but simply an extension of our present methods. Accordingly, in 1956, we established a study group composed of about 25 staff members of the Physics Department and the Hansen Laboratories of Physics at Stanford. This group met regularly, devoting their own time to the project, to work out in detail the specifications of a machine of this sort. The result of the work of this study group was the submission to three agencies of the government, in April, 1957, of a document entitled, "Proposal for a Two-Mile Linear Electron Accelerator." Although some of the aspects of this proposal have been revised in certain ways (to which I shall refer

later), this document is still the main source of information about the project, and by far the greater part of its contents still represents our best thinking on the various aspects of the proposed machine. Our 1957 proposal was based on the belief that a linear electron accelerator capable of providing an intense beam of electrons at energies up to 45 Bev was needed to supplement other national facilities in advancing research in the field of high-energy particle physics.

Following our submission of this 1957 proposal, a number of other related steps have occurred. I shall review these briefly here to bring the matter up to date. The consulting firm of William Brobeck and Associates reviewed our proposal, at the request of the Atomic Energy Commission, in 1958. This review, dated June, 1958, constitutes a second major reference source of information about the project. I shall discuss some of the points which the Brobeck review raised in a later section of this statement.

I should like to note also that our proposal has received thorough consideration by a number of government agencies and by many physicists. In the course of the final review by the Atomic Energy Commission and by the Panel on High-Energy Accelerators, headed by Dr. Piore, and appointed by the President's Science Advisory Board, certain "ground rules" were decided upon which have affected the scope and intent of our proposal to some extent. These ground rules will also be discussed in our present statement.

Since some modifications of our original proposal have been made, I should like to summarize here briefly the specific machine which is now proposed. The accelerator would be approximately two miles long,

and would be powered, to start with, by 240 klystron tubes. When operated at the conservative output of six megawatts per klystron, the energy output from the accelerator would be 10 Bev. The klystrons will be designed to provide a maximum output of 24 megawatts, thus making the maximum available energy approximately 22.5 Bev. The normal conservative operating range of the machine will be in the 10 to 15 Bev range, though experiments which are important enough to justify greater operating costs can, no doubt, be conducted at or near the maximum energy of the machine. It is important to note that the combination of the stated length, conservative klystron power, and the desired energy range of 10 to 15 Bev is arrived at on the basis of economic studies, including the important question of operating costs. The by-product of the conservative and economical initial design, however, is the fact that by increasing the number of klystrons to an eventual 960, the ultimate energy of the machine could be raised to about 45 Bev. The increase in number of klystrons and the resultant increased energy could be provided when it is determined that the usefulness of the machine in research has sufficiently high scientific value to justify the cost of additional klystrons and the correspondingly greater operating costs (see tabulation of design parameters.) The machine would be located in two parallel tunnels on a 400-acre site which has been reserved by Stanford University for this purpose. (An aerial photograph of the site is shown in Figure 1.)* The estimated cost of construction is $105 million (see Figure 2), with an additional $18 million proposed for the necessary preliminary engineering and related work. It is expected that the construction period would be six years, from authorization of the project to the day that research with the machine could begin.

*Figure captions are shown on the back of each figure.

DESIGN PARAMETERS

	STAGE I	STAGE II
ACCELERATOR LENGTH	10,000 FEET	10,000 FEET
NUMBER OF KLYSTRONS	240	960
TOTAL KLYSTRON POWER (R.F. PEAK)	5760 MEGAWATTS	23040 MEGAWATTS
MAXIMUM ELECTRON ENERGY	22.5 BEV	45 BEV
MAXIMUM BEAM POWER (AVERAGE)	0.6 MEGAWATTS	2.4 MEGAWATTS
MAXIMUM PULSE RATE	360 PER SECOND	360 PER SECOND

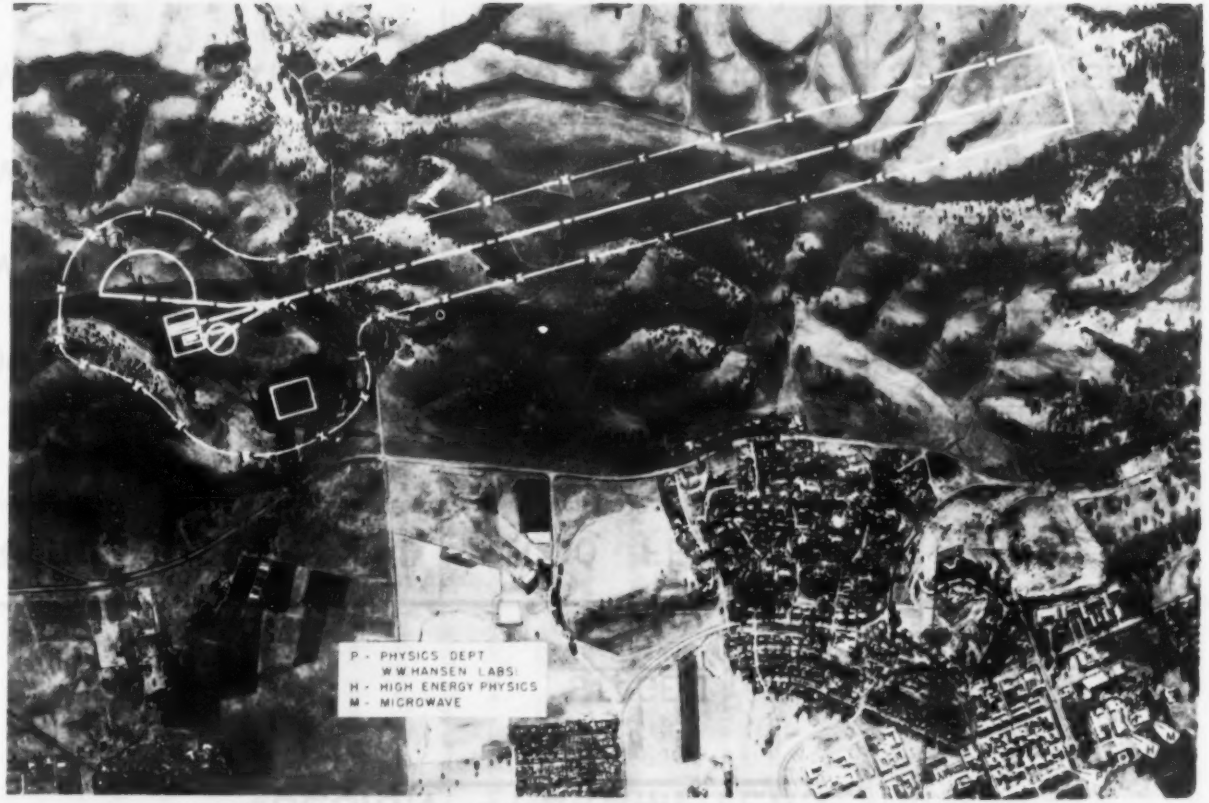

FIGURE 1. - Aerial photograph of the proposed accelerator site

STANFORD UNIVERSITY

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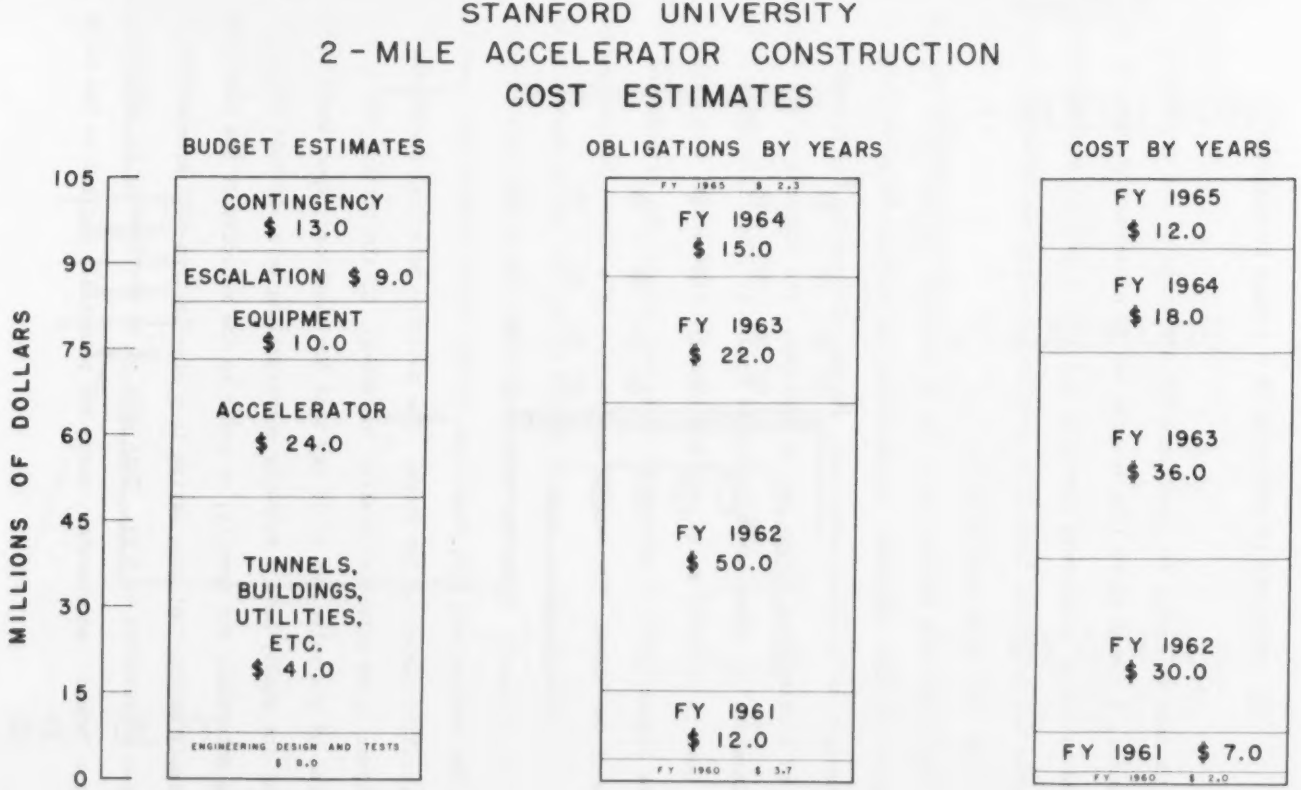

FIGURE 2. - Construction cost estimates for the proposed two-mile accelerator at Stanford University

II. PRINCIPLE OF OPERATION OF A LINEAR ACCELERATOR

To make it easier to understand the operation of the two-mile accelerator, I should first like to give you an elementary picture of the method we use to accelerate electrons and also a general description of a simple but practical form of an accelerator which constitutes a "building-block" for large accelerators.

There are many methods which can be employed to accelerate charged particles to high energies. Acceleration can be made to occur either in straight or circular paths; and, static, alternating, or a combination of accelerating forces can be employed. The simplest of all "linear accelerators" is shown symbolically in Figure 3. This is a diode of the kind used in ordinary radio sets and in medical or dental x-ray tubes. In the figure shown, a battery is connected between the cathode and anode of the diode. The cathode may consist of a nickel button, painted with a suitable material, such as barium oxide, and can be heated by an electric filament. Under the influence of heat, electrons are emitted from the cathode and find themselves in the vacuum between the negative and positive plates of the diode. The positive potential causes the electrons to be attracted towards the anode. If the battery has a potential of six volts, we could say that the electrons, upon their arrival at the anode, have a velocity corresponding to a six-volt accelerating potential; for brevity, we refer to the velocity of the electrons by simply saying that this device is a six-electron-volt accelerator, further abbreviated as 6 ev. This kind of an accelerator is referred to as a "static" accelerator, since the potentials applied to the diode

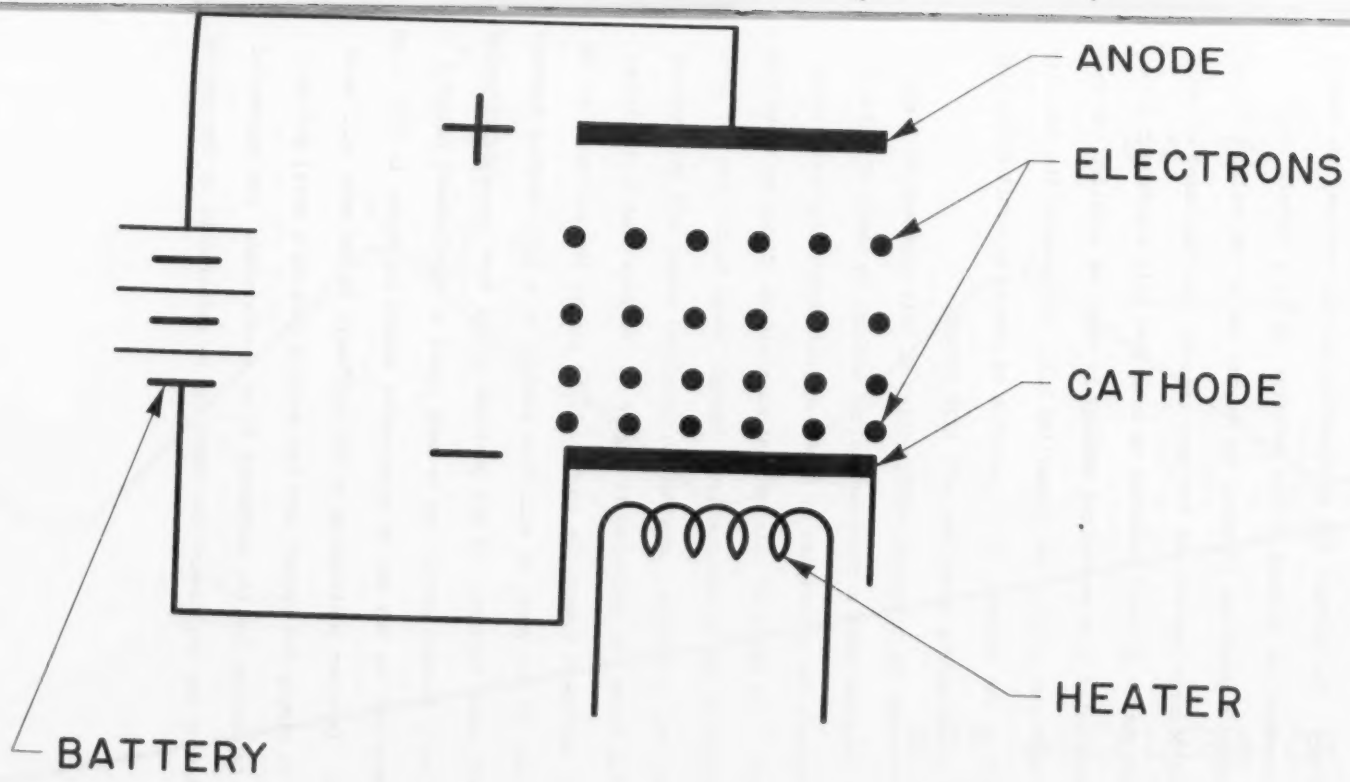

FIGURE 3. - An electronic diode, the simplest form of an "electron accelerator"

(and hence to the electrons) are in the form of a steady force supplied by the battery. To increase the acceleration in this device, one merely needs to increase the voltage of the battery. Up to a certain limit, this is indeed a practical process; but beyond one or two million volts, the process becomes impractical for many reasons, not the least of which is its high cost. It is of interest to note that this electronic diode can be represented by a mechanical analogy in which we consider the rolling of a ball down a hill: the higher the hill, the greater the velocity of the ball at the bottom. It is possible to obtain an arbitrarily high velocity if one merely makes the hill high enough.

To overcome the practical difficulties of this approach at higher energies, consider next a crude mechanical analogy by means of which I hope to explain the principles of the so-called "traveling-wave linear accelerator." By means of this mechanical analogue it can be shown that great velocities can be obtained even though "large hills" are not used. To explain this principle, consider an idealized ocean wave progressing towards the shore, as indicated in Figure 4. Suppose that a boy wishes to ride a surfboard toward the shore. If he places the surfboard on the forward part of the wave, he will find himself on a hill sloping downward and he will move forward. If his position on the wave is selected properly, the boy's forward motion can be made equal to the forward velocity of the wave and the boy can be accelerated toward the shore in this fixed position. Improper positioning of the surfboard on the wave will cause the boy to simply bob up and down (as would a cork on a wave) and will make it impossible for the surfboard to be accelerated. The successful navigation of the boy toward the shore can be referred to as the process

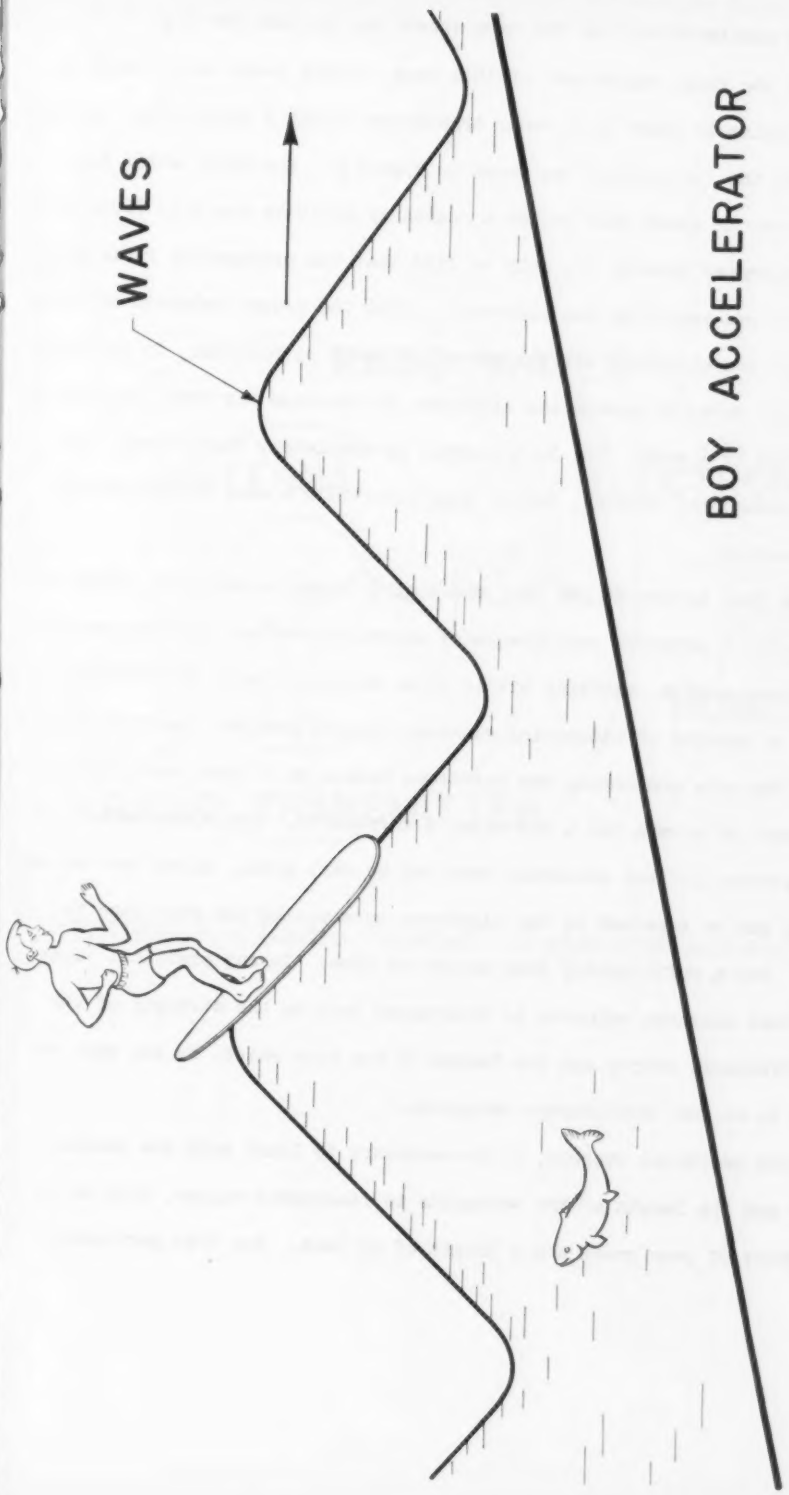

FIGURE 4. - Boy accelerator

of "boy acceleration;" as the wave speeds up, so does the boy.

In the radio equivalent of this case, strong radio waves could be establishing in space by a radio transmitter which I shall refer to henceforth as the "rf source," as shown in Figure 5. Electrons which find themselves in space just behind a region of positive electric field will be accelerated towards it, only to find that the propagating radio wave tends to run away from the electrons. With the proper relation of velocities of the electrons and the waves, it would be possible, in principle, for radio waves to accelerate electrons in the same way that a boy is accelerated by a wave. The last example is completely impractical, for many fundamental reasons, but it does illustrate a step in the process of reasoning.

We thus arrive at the last model of a linear accelerator, shown in Figure 6. A powerful radiofrequency source introduces radiofrequency power into a pipe, exciting within it an electric field distribution which is capable of attracting electrons toward the most positive point along the axis and making the electrons behave as if they were riding the crest of a wave (as a boy rides a surfboard). The forces which act on electrons in this structure need not be very great, since the desired energy can be imparted to the electrons by exposing the electrons to waves for a sufficiently long period of time. In any practical case, the final electron velocity is determined both by the strength of the radiofrequency source and the length of the pipe which, by the way, we refer to as the "accelerator waveguide."

For practical reasons, it is necessary to limit both the maximum power and the length of the waveguide to reasonable values, such as 24 megawatts of peak power and a length of 10 feet. For this particular

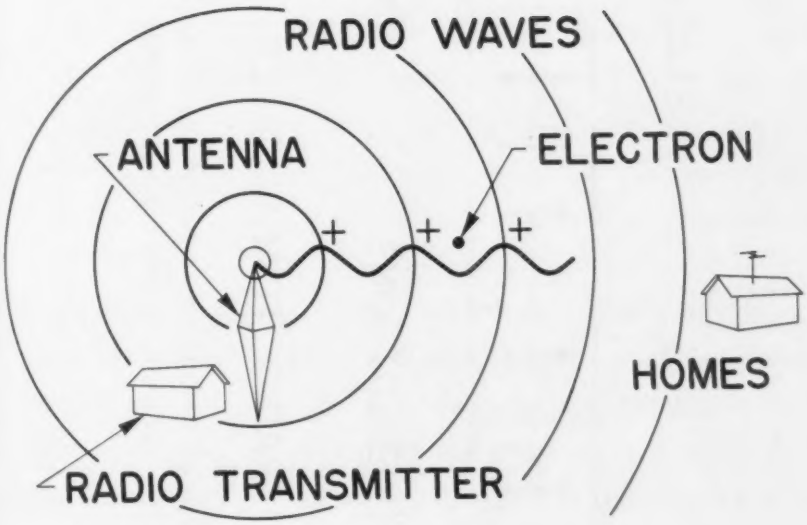

FIGURE 5. - Radio "model" of electron accelerator

FIGURE 6. - An idealized form of a linear electron accelerator. An electron gun injects electrons into a pipe which carries intense radio waves

set of numbers, typical of the maximum values we suggest for our new machine, acceleration of electrons results in an energy of 45 million volts, or a velocity of 99.994% of the velocity of light. (You are, no doubt, aware of the fact that acceleration of electrons is, in fact, something of a misnomer, since the velocity at even a few million volts causes the electrons to travel at very nearly the velocity of light and the process of acceleration results primarily in an increase in the mass of the electrons. In the example just quoted, at an energy of 45 Mev, the mass of the electrons at the end of a ten-foot waveguide becomes approximately equal to 90 times the initial mass of the electron.)

Thus, an electron can be made to gain energy at the expense of power supplied by the radiofrequency field and, if the power and length are sufficient, substantial electron energies can be obtained with only a moderate axial field in the waveguide. Thus, even though we propose to build a machine in which the electron energies may approach 45 billion volts, there are no correspondingly large electric potentials anywhere in the accelerator. In this respect, the linear electron accelerator resembles many of the circular particle accelerators where, by repeated passages through an accelerator gap, only moderate radiofrequency voltages are needed to produce the large final particle energy.

As mentioned above, reasonable values of radiofrequency power in an accelerator waveguide result in substantial particle energies, but these are still far below our eventual goal of 10 to 45 Bev. Fortunately, it is possible to arrange accelerators of the kind I have described in a straight line, one after another. If the first of these accelerates electrons from 0 to 10 Mev, the next will accelerate them from 10 to 20 Mev, the next from 20 to 30 Mev, and so forth. The final energy becomes

proportional to the number of accelerators in operation. Thus, to obtain an energy of 45 Bev, one would need to use 1,000 accelerators in a line, each one operating at 24 megawatts and being 10 feet long. This would lead, then, to a total length of 10,000 feet and a total radiofrequency power of approximately 24,000 megawatts. A lower energy, as is often desired, can be obtained from such a machine in a number of ways. The simplest would be to reduce the radiofrequency power, a process which is the most attractive because it reduces the amount of power needed and, therefore, the operating costs. Lower energies can, of course, be obtained with a shorter length of accelerator. The proper relative choice of length and power is one of many economic factors which must be taken into account carefully.

The accelerator waveguide, shown in Figure 7, is a copper pipe, approximately four inches in diameter, divided into compartments approximately one inch long. The purpose of subdivision of the pipe into compartments is to control the velocity of the wave so that at all points throughout the length of the machine, the electrons find themselves in the region of greatest accelerating force. In the case of the boy accelerator, the clever boy manages to keep himself in the proper position along the wave; the inanimate electrons cannot do this, making it necessary for the designer of the machine to calculate ahead of time the velocity of the electron everywhere along the length of the machine, inch after inch, and to make the velocity of the waves at each point equal to that of the electron. Although this mathematical process is simple, it results in exceedingly small mechanical tolerances for fabrication, making it necessary to keep the dimensions of the compartments to approximately one-tenth of one thousand of an inch. Fortunately, we have been able to

FIELD LINES INSIDE ACCELERATOR

FIGURE 7. - Section of the accelerator waveguide, showing the lines of electric force of a propagating radio wave

devise a process which makes the fabrication problem quite straightforward.

The last feature of a linear electron accelerator which it is important to understand is the question of orbit stability. It might be assumed that getting the electrons to pass through a pipe 3/4 of an inch in diameter and two miles in length is an insurmountable problem. Even if the pipe were absolutely straight (which, in practice, is impossible), it is virtually impossible to aim the electron gun at the beginning of the machine so accurately that the electrons will pass through such a small pipe. Fortunately, these difficulties are more apparent than real for two reasons. First, the difficulty mentioned is not based upon accurate reasoning because the effects of relativity have been neglected. According to the theory of relativity, an observer traveling with the electrons would see the pipe greatly foreshortened, simply because everything approaches the observer with nearly the velocity of light. However, the transverse dimensions of the accelerator are not altered, making the apparent 3/4 inch hole retain the same dimension, regardless of the axial electron velocity. Figure 8 shows a chart indicating the degree of foreshortening of the accelerator. For example, if we assume that our machine is to be 10,000 feet long, then we find that at an energy at 45 Bev the accelerator appears to be only fifteen inches long! Thus, the problem of getting an electron through a hole 3/4 inch in diameter and fifteen inches long is a trivial one - at least as compared to the precision needed in painting an accurate picture on a screen of a television picture tube.

Further, the straightness of an accelerator is not a particularly

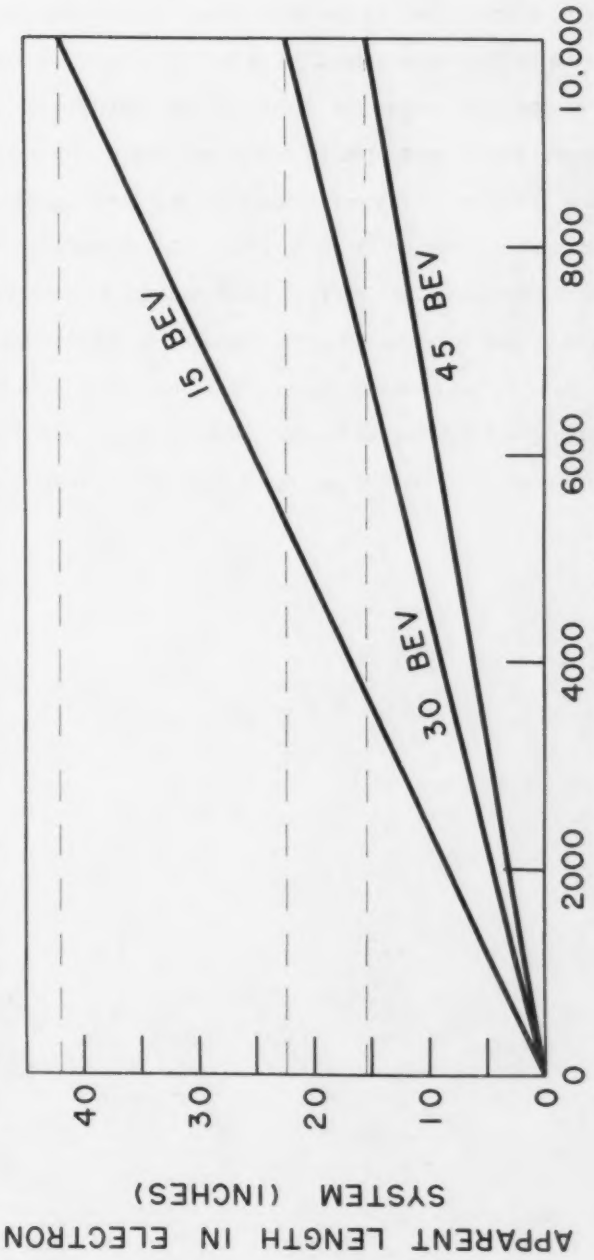

FIGURE 8. - Relativistic foreshortening of electron linear accelerator. Curves are marked with the values of electron energy at the end of the machine

important matter because relatively simple means can be used to redirect the electrons if a small bend in the pipe occurs. This kind of a correction can even be done automatically, by providing devices which sense the location of the beam inside the waveguide and apply corrective forces by electromagnets spaced periodically along the length of the machine.

Although a practical accelerator contains many more components than have been mentioned in this brief description, all of these represent simple electrical or mechanical devices, well understood by those skilled in building radar-type devices. For this reason, no special mention of these will be made in this presentation, other than to observe that provision of reliable and economical vacuum, water cooling, and other components and systems represent a significant engineering task.

III. ACCELERATOR DEVELOPMENT AT STANFORD UNIVERSITY

Although the development of the linear accelerator at Stanford has been a long range group effort, its beginning can be traced directly to the interests of the late Professor W. W. Hansen (1909-1949) in x-ray research and nuclear physics. Professor Hansen received his undergraduate and graduate training at Stanford University, specializing in x-ray research. After a year and a half spent at MIT and at Michigan, Professor Hansen returned to Stanford in 1934 to begin a program of research of his own. At that time, at Stanford as well as elsewhere, the interest in conducting research in nuclear physics rose to a new height as a result of the powerful stimulation created by Chadwick's discovery of the neutron in 1932 and the successful experiments of Cockcroft and Walton in producing nuclear transmutations by artificially accelerated particles. These and other earlier researches made it seem desirable to undertake the construction of new high-energy particle accelerators capable, perhaps, of accelerating electrons or protons to a few million volts or more. In view of the experience at Stanford with x-rays, it seemed natural to Hansen to try to accelerate electrons, rather than protons or other heavy particles (which was already being done at other Universities, principally at the University of California). Hansen's research soon led to the discovery of the "rhumbatron," an empty copper container which, as Hansen proved, could be made to act as an excellent radiofrequency resonant circuit, capable of developing extremely high voltages with the consumption of only a moderate amount of radiofrequency power. The work of Hansen in '36 and '37 served to test his early theories but did not come to a useful end at that time

for two unrelated reasons: the arrival at Stanford of the Varian brothers and the subsequent invention of the klystron; and Kerst's successful development of the betatron. Kerst's methods, so eminently successful, made it appear that Hansen's radiofrequency linear accelerator concept could not compete with the simple transformer action of the betatron, certainly not without finding then unknown sources of high radiofrequency power.

The arrival of the Varian brothers produced a profound change in research activities in this field at Stanford and was destined to play a very important role. Because of its importance, a few remarks might be appropriate at this time. The elder brother, Russell Varian, was a graduate student with Bill Hansen at Stanford and, upon completion of his graduate studies, he had pursued radio and television research in one of the eastern industries. His younger brother, Sigurd Varian, was a pilot for Pan-American Airways at that time. In the course of his daily work, Sigurd Varian recognized the limitations of the existing navigational aids and wished to find, among other things, a method of safe blind-landing. He was also very much aware of the threat posed by the rapidly developing German Air Force and the possibility of devastating air attacks. At that time there was no effective way to combat airplane raids that could easily be staged in bad weather or at night. In looking for answers to these questions, Sigurd Varian discussed them with his brother Russell who immediately realized, from basic physical principles, that the only effective way to solve both of these problems would be to invent methods of generation and detection of radio waves in the centimeter region - waves which could be focused into beams like search-light beams, and which would not be disturbed by atmospheric conditions.

The Varian brothers decided to attack these problems, and they established a private laboratory in a small village on the California Coast. They soon realized that their efforts were not advancing rapidly enough, and they decided to go to Stanford where they might benefit from the atmosphere of stimulating scientific discussion and where they knew Professor Hansen was already experimenting with novel microwave devices.

Professor Hansen and others at Stanford were very receptive to the Varian ideas, and arrangements were made to have the Varian brothers conduct their researches in the Physics Department of the University, without salary, and with an allocation from the University of $100 for materials and supplies.

In 1937, after several months of work, Russell Varian had invented 22 different schemes and had recorded these in his notebook. Each one was evaluated by Professor Hansen and found to be inadequate in one regard or another. In trying to assess his inventions, Russell Varian came upon a principle which seemed to be the answer to the fundamental limitation of all known ways of generating very short wavelength radiation - the so-called "transit-time" effect. The next invention that occurred to Russell Varian could not be discounted by Hansen, and after a number of spirited arguments it was agreed by all that the scheme was probably workable.

Design of the new invention started immediately; with Hansen's knowledge of rhumbatrons, there appeared in a little over a week, a sketch which was to become the blueprint for all the klystrons which are now in use. The construction of the model was made possible by Sigurd Varian's skillfulness, and in a very short time the device was operating and generating microwaves.

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The Varian invention of the klystron soon reached the attention of the Government and of several industrial firms, and led to the rapid development of the klystron as used in the World War II radars. The klystron very quickly became an important part of the radar developments in England and in the United States and played a vital role in the successful air defense of Great Britain and in the ultimate air superiority of the Allies during the War.

Although the above remarks are clearly outside the scope of the present hearings, they do set the stage for the following activities of the Stanford personnel. During the War, the Stanford group was asked to help establish the Sperry Gyroscope Company's electronics laboratories, and they played an important part in developing various types of radar systems.

At the end of the War, Professor Hansen, together with E. L. Ginzton and J. R. Woodyard, examined the former conclusions regarding the feasibility of building high-energy linear accelerators. This group, among several others, recognized that the war-developed magnetrons made it practical to build linear electron accelerators in the range of several Mev. It was also quite evident that any higher energies would require further development of power sources in order to obtain the power needed to equal or surpass the circular accelerators: the synchrotron and the betatron. During the years 1946-47 Professor Hansen and his colleagues were able to demonstrate, both theoretically and practically, that the acceleration process was feasible. In 1947 electrons were accelerated, and eventually a 12-foot machine, known as the Stanford Mark I, was constructed, and it produced 6-Mev electrons when powered by a single one-megawatt magnetron at a wavelength of ten centimeters.

The early success of this project at Stanford (as well as elsewhere*) did not obscure the fact that sources of higher peak power were badly needed. With this in mind, and aided and encouraged by the Office of Naval Research, Professors E. L. Ginzton and M. Chodorow began to explore possibilities of generating higher power. As a result of their war-time experience in klystron research, the Stanford group decided to explore the potentiality of klystrons. Professor Chodorow investigated the theory of operation of klystrons at relativistic velocities and found that nothing would preclude their operation in the multi-megawatt range. With a view toward the possible utility of multi-megawatt klystrons in a large linear accelerator, and in high-power radar use, the Stanford group began to explore possibilities of such a klystron. A successful high-power klystron was finally fabricated and tested, in the spring of 1949, which demonstrated that power in the range of tens of megawatts was indeed practical.

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*The availability after the war of microwave techniques and of tubes capable of supplying high peak-power caused several other laboratories to undertake work on the problem of electron acceleration. Groups which made early contributions were active at: General Electric Company, The University of Virginia, Purdue University, Yale University, MIT, TRE (England), Muiland Research Laboratories (England), and the Radiophysics Laboratory (Australia). All of these laboratories worked with machines in the energy range below 20 Mev. In recent years, a number of industrial firms have been developing machines for industrial, medical and other applications. Firms known to be active include High Voltage Engineering Co., General Electric Co., Applied Radiation Co., Varian Associates, and Hughes Aircraft Co., all in the United States; and Metropolitan Vickers, Ltd., and Mullard, Ltd. in England. Also, the Vickers Group in England has suggested the construction of a 20-Bev machine, not unlike the Stanford proposal.

It is understood that the USSR is building a Stanford-like accelerator at 4 Bev. Serious consideration is also being given in Holland to the construction of a 3-Bev machine for the University of Amsterdam. The University of Paris is in advanced stages of construction of a 1-Bev machine, expandable in the future to 2 Bev. In

Anticipating the almost certain success in klystron development, a proposal was submitted to the Office of Naval Research in 1948 for construction of a billion-volt linear electron accelerator. This proposal, framed by Hansen, Ginzton, and Chodorow, was supported by E. Piore of the Office of Naval Research. This project obviously involved some uncertainty, since little previous experience was available, both in the generation of very high power and in accelerating electrons in the proper manner. The proposal was approved, and the construction of the billion-volt accelerator, now known as the Stanford Mark III, was begun in the winter of 1949 and was substantially completed in the spring of 1952. (A photograph of the Mark III is shown in Figure 9.) The accelerator worked successfully from the first moment it was tried. Partial operation was begun in 1951 with the first 80 feet of the 220-foot machine in place. Extensive research in physics was begun at that time. Competition for available funds between physics research and the continued construction has in large measure determined the rate of progress in attaining the final billion-volt goal. It can be noted that the 220-foot machine, powered by twenty-two seventeen-megawatt klystrons, has been in constant operation and is currently being extended to 300 feet to make it possible to attain an energy of approximately 1 Bev.

Perhaps it is not inappropriate to mention that the development of the accelerator and its klystrons led to a number of important

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nearly all of these cases, the large machines are either patterned after the Stanford machines, employ Stanford-trained personnel, or have borrowed Stanford staff members for restricted periods of time.

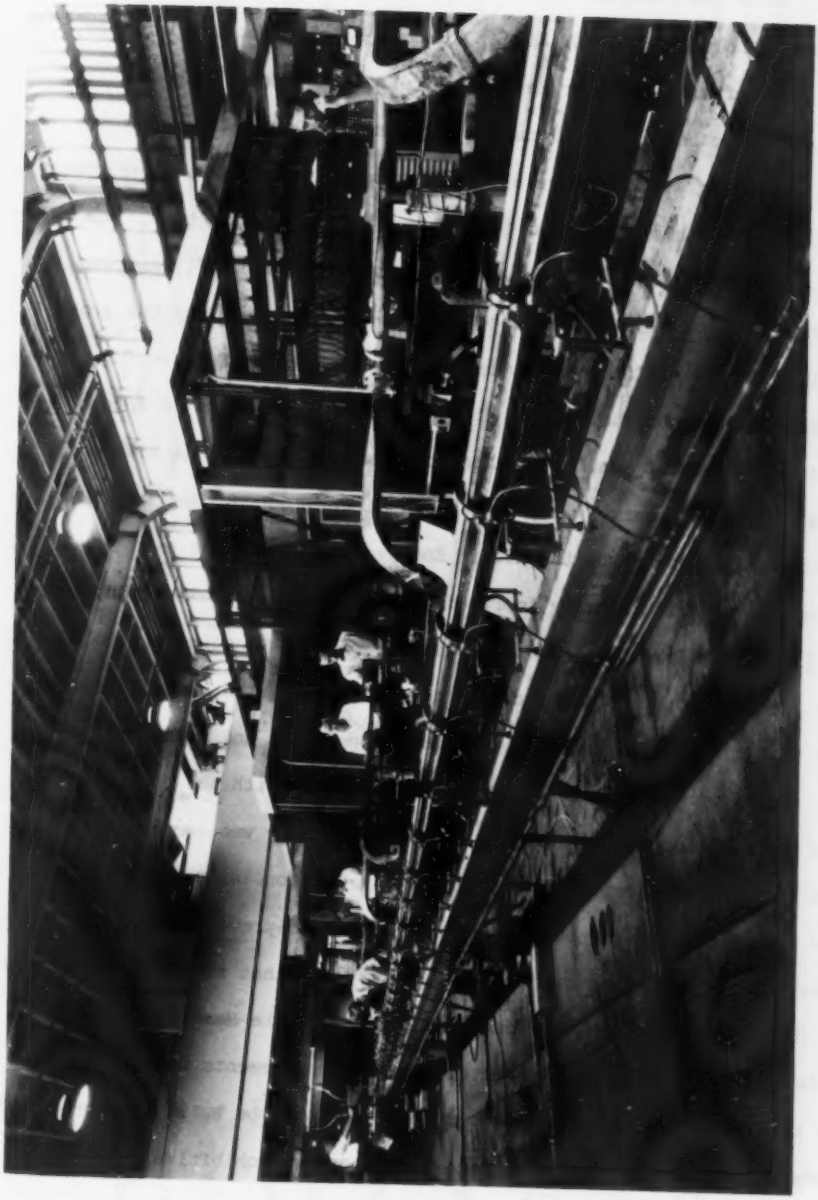

FIGURE 9. - Photograph of Stanford Mark III accelerator

by-products. The high-power klystrons have now been built for a number of different wavelengths and different sizes for several defense applications, including the DEW Line. A number of electron accelerators, patterned after this major development, have also been built for medical and other applications and are listed in Table I.

Table I gives some idea of the continuous research and development activity which has gone on at Stanford up to the present time. One of the accelerators listed in this table, namely the Mark IV, deserves special mention. Construction of the Mark IV was sought by our group in 1954 for two different reasons: to study methods of improving accelerator components; and to study problems which might be encountered in construction of a multi-billion-volt machine, such as is now being considered. The Mark IV machine, operated by Dr. R. B. Neal and his group, and supported by the Atomic Energy Commission, has been invaluable to us in establishing many improved methods of design and construction of linear accelerators, and now forms one of the two cornerstones of our present proposal (the second being, of course, the Mark III accelerator with its very satisfactory record of operation and research).

Our interest in the multi-Bev project began with the completion of the Mark III machine. The first feasibility study was completed in 1954 and resulted in a report on that subject. The conclusion of this report was that there were no basic reasons which would prevent successful operation of a machine two miles in length, and that an energy of perhaps 50 Bev could be attained. Continued support of the Mark IV activity under AEC sponsorship has resulted in many improvements which encouraged us to believe that a machine two miles long could be built in a practical form, and that its operating costs would not be prohibitive.

TABLE I

TABLE I

LINEAR ACCELERATORS CONSTRUCTED AT STANFORD

NAME	DATE COMPLETED	MAXIMUM ENERGY	ACTIVE LENGTH	POWERED BY [a]	USE
Mark I	1947	6 Mev	12 ft.	0.9 Mw magnetron	(Dismantled)
Mark II [b]	1951	49 Mev	10 ft.	20 Mw klystron	Prototype for Mark III. In use in nuclear research.
Mark III[c]	1952	730 Mev	214 ft.	22-20 Mw klystrons	In routine use for nuclear research.
Mark IV	1955	80 Mev	20 ft.	2-20 Mw klystrons	"Prototype" for M; component development; β-ray cancer therapy.
"Motz" accelerator	1954	2 Mev	3 ft.	1 Mw klystron	Research on millimeter-wave radiation from electrons. Now in use at Oxford University.
Medical accelerator	1955	5 Mev	6 ft.	1 Mw klystron	X-ray cancer therapy at Stanford Hospital.
Medical accelerator (G.E.)	1957	5 Mev	6 ft.	1 Mw klystron	Built for G.E. for experimental use.
Michael Reese accelerator[d]	1954	35 Mev	10 ft.	1-15 Mw klystron	β-ray therapy at Michael Reese Hospital, Chicago
University of Chicago accelerator[e]	1954	60 Mev	20 ft.	2 15 Mw klystrons	β-ray cancer research at Argonne National Laboratory.
X-band accelerator	1957	3 Mev	2 ft.	1-1 Mw 3 cm klystron	Research on millimeter-wave radiation from electrons.

For footnotes referred to by superscript letters, see next page.

TABLE I FOOTNOTES

(a) All power sources operated at a 10.5-cm wavelength unless otherwise indicated

(b) Mark II was modified in 1958 to use recently developed electroformed accelerator sections.

(c) Now being extended to 305 ft., 31 klystrons, to deliver 1.0 Bev. Mark III now consists of 19 ten-foot sections and 3 eight-foot sections.

(d) Some components built by Helene Curtiss Industries, Chicago.

(e) Some components built by High Voltage Engineering Co.

The possibility of constructing a two-mile multi-Bev linear electron accelerator was first considered formally at Stanford in the early part of 1955. Members of the Physics Department group, including Professors Bloch, Ginzton, Hofstadter, Panofsky, and Schiff met several times during the course of that year to discuss the scientific justification for such a project and the general problems that would be involved in its construction. In April of 1956 a larger group met, composed primarily of the members of the W. W. Hansen Laboratories of Physics, and agreed to undertake the more detailed study which led to this proposal. The present proposal is the result of the part-time effort of approximately twenty-five people working over a period of a year at Stanford and of voluntary contributions on the part of several other organizations. The latter included Utah Construction Company and Bechtel Corporation, which made extensive independent studies of the site and tunnel problems and submitted completed reports on their respective solutions. Varian Associates was one of the firms which was generous with its time in furnishing cost estimates for construction and operation of a klystron facility and the cost of fabrication of klystron tubes. Many other individuals and organizations provided important help in arriving at our final proposal.

The final document describing our intentions was submitted to the Government in April of 1957. Our efforts to improve our knowledge of the design of linear accelerators have been continued since then under AEC auspices and have resulted in the firming-up of costs, improved reliability of klystrons, and in many other advances.

It is our hope that this review will serve to indicate some of the ways in which we have been continuously involved in microwave

research since the mid-thirties, and that the ten linear electron accelerators which we have built at Stanford will demonstrate our continued interest in this field and our experience in converting these basic ideas into operating instruments.

IV. PURPOSE AND CHARACTERISTICS OF THE PROPOSED ACCELERATOR

A. Scientific Objectives:

During the past two decades workers in the fields of cosmic rays and high-energy physics have shown that matter consists not only of the "classical" particles, electrons, protons, neutrons, and photons, but also of a large number of new, seemingly basic particles and their opposites, the anti-particles. Altogether, there are now believed to be about 14 particles lighter than the proton and 16 particles equal to or heavier than the proton. Because of energy limits in presently available accelerators, some of the heavier anti-particles have not yet been observed but are predicted on general theoretical grounds. As yet, the nature of these particles is far from understood, and the pursuit of such understanding is one of the most important and challenging tasks facing physicists at the present time. The only known method of obtaining these elementary particles in sufficient quantity for detailed study is by the use of high-energy accelerators. This is the reason why these machines have assumed such an important and unique position in the field of scientific instruments.

As Professor Schiff of Stanford discussed with the Committee last year, the motivation for the extension of accelerators to higher energies is twofold: the desire to gain more knowledge about the methods of production and the detailed interactions of known and postulated particles, and the expectation of revealing basically new phenomena not predicted by any present theories. Indeed, it is not at all clear whether the anticipated discoveries will consist of additions to the known species of particles, or the clarification of the

present rather jumbled picture by revealing new symetries and greater order in particle physics, or the discovery of entirely new and revolutionary laws or concepts which will cause a major upheaval in the entire realm of physics and related fields. Justification of higher energy accelerators is strong on all of these counts. It should be added that the rate of progress of science is such that the anticipated field of research for a particular machine has often changed in character either during its construction period or shortly after the machine has been put into service as an experimental tool. This inability to predict exactly what will happen is, of course, the very definition of basic research.

In the history of high-energy accelerators, many different machines have contributed valuable results. For example, in the case of pion physics the multiplicity of results obtained with machines of diverse characteristics has led to at least a semi-quantitative understanding of an entirely new field of physics in the space of a few years. Proton machines were first used to study some of the systematics of pion production. Because of the large cross-section for new particle production by protons, these machines were able to serve as sources of pions for scattering and absorption experiments. On the other hand, because the production of new particles by photons is basically easier to analyze than that by protons, the electron machines were most useful in the study of these processes. Together, these different types of machines made much greater progress in this field than either could have made alone. This is an example where diversification of attack upon a given system has led quickly to greater understanding. Although

it is unlikely that at the high energy levels the relative suitability of electron and proton machines will continue to be based upon the same factors as in the case of pion physics, we are convinced of the continued desirability of having machines with varied characteristics (such as different incident particles, beam geometrics, beam energies, beam intensities, and beam programming in time) rather than simply attempting to use a single type of machine for all purposes.

While bearing in mind the previous statement that the trend of scientific investigation is not always predictable, we should like to point out certain fundamental kinds of experiments that could, and almost certainly would, be performed by the proposed accelerator. There are several general applications for particle accelerators: (1) as a controlled source of secondary beams of artifically produced particles which may be used in further study of interactions; (2) as a source of primary particles to study nuclear structure; (3) as a tool to study the basic production processes in the creation of particles; and (4) as an instrument to study the high-energy limit of quantum electrodynamics (this applies only to electron machines).

A beam of electrons produces approximately 1/30 as many new particles as does a beam of protons of equal intensity. However, as shown in Fig. 10, the attainable electron beam current with the proposed accelerator is approximately 10,000 times as high as that of any other machine being designed or constructed in the same energy range. Thus, the proposed accelerator should be a much more abundant source of artificially produced particles than any of the other machines.

Because of its smaller rest mass, an incident electron provides

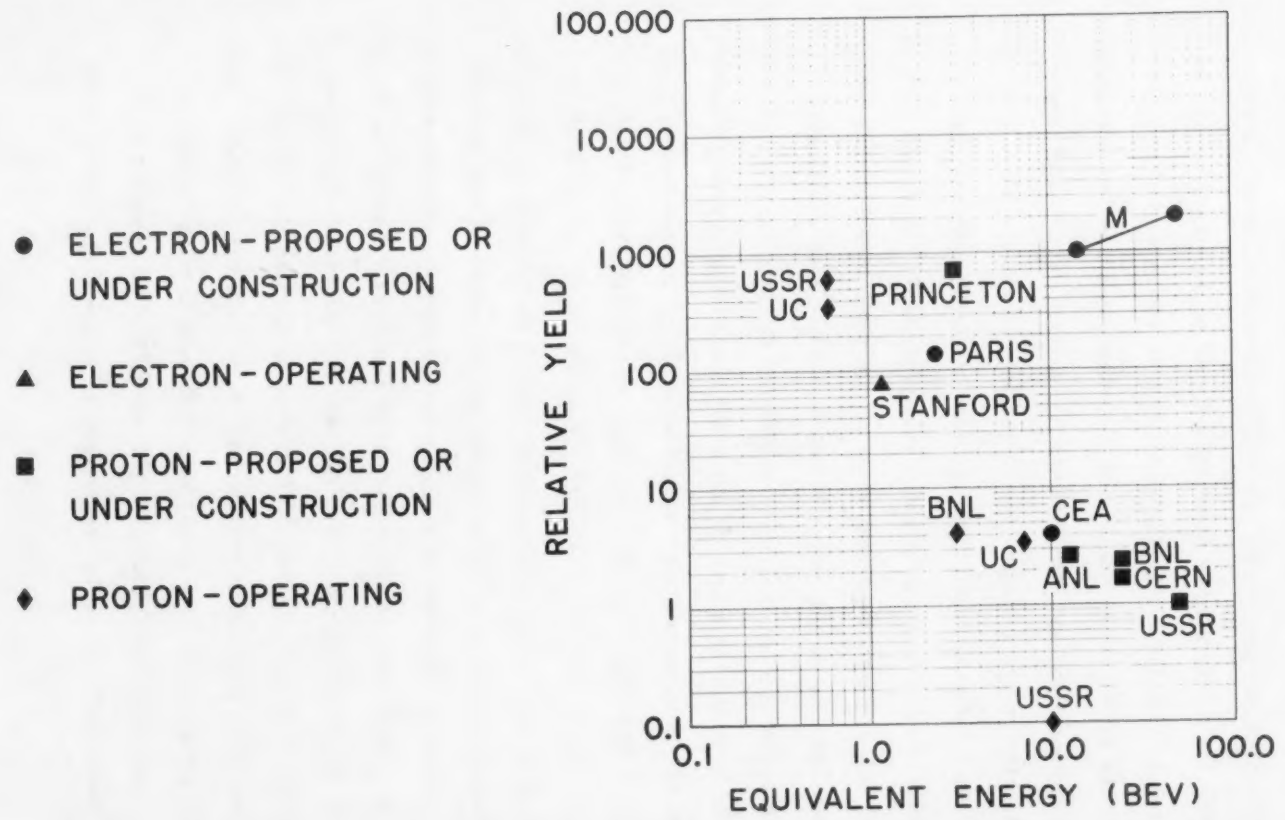

FIGURE 10. - Relative beam energy and intensity of various accelerators

a larger center-of-mass energy than an incident proton having the same kinetic energy. For example, a 15-Bev electron striking a target proton gives the same center-of-mass energy as an incident 19.5-Bev proton. Similarly, a 45-Bev electron is equivalent to a 53-Bev proton. This means that the energy threshold for production of new particles by electrons is lower than the corresponding threshold for protons. The center-of-mass energies and thresholds for the production of various particles and anti-particles by incident electrons and protons is shown in Fig. 11. The thresholds for all known particles are such that an energy of 7.5 Bev is sufficient to start producing these particles. However, the measurement of production cross-sections over energies above threshold might reveal specific new physical information, as has been recently observed in the case of single photoproduction of pions in the Bev region.

A series of experiments of the second class listed above has been carried out by Hofstadter and his colleagues on the 700-Mev Stanford Mark III accelerator. These significant experiments, which involve elastic scattering of electrons, have measured more accurately than ever before the distribution of charge and magnetic moment in a large number of nuclei. Similar measurements have also been made on the proton and the neutron. With the proposed machine, the available energies of the bombarding electrons will be much higher, and their effective de Borglie wavelength will therefore become shorter. Thus, it will be possible to study the structural details of nuclei and individual particles with increasingly higher resolution.

Other potential experiments involve the study of the production

FIGURE 10. - Relative beam energy and intensity of various

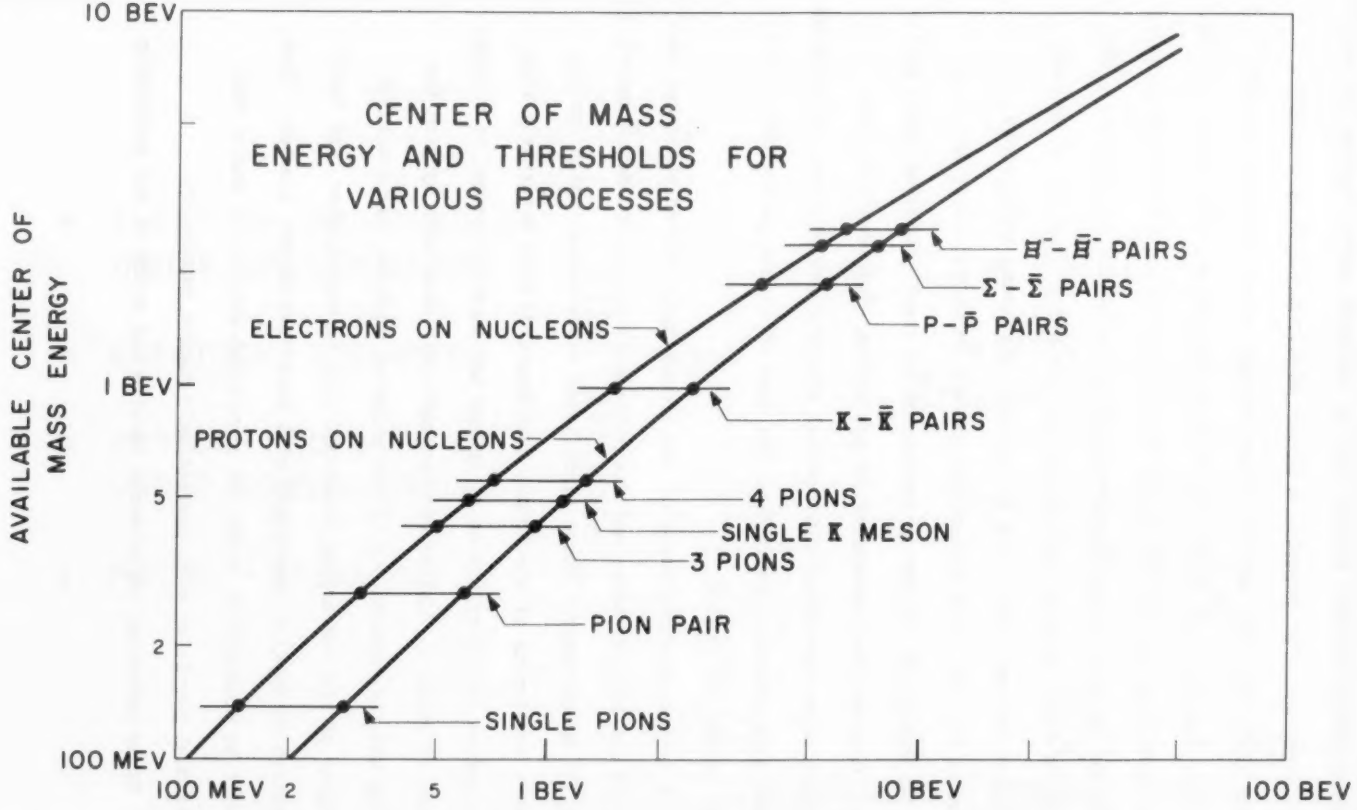

FIGURE 11. - Center of mass energies and thresholds for various processes

processes of new particles in inelastic-scattering experiments. As pointed out in the discussion of pion physics, the photoproduction process is in general less complex than the corresponding heavy-particle production process. An additional advantage possessed by the linear electron accelerator is the availability of a well-collimated electron beam. The ratio of cross-sections for electron-induced to those of photoproduced processes gives additional valuable information.

Two additional experiments which can be performed only with incident electrons are of interest. An important reason for increasing energies from electron machines to higher levels is the study of the electromagnetic interaction itself. At the energy levels we are aiming for, it is possible that deviations from the present formulation of electrodynamics will be encountered. There is reason to suspect that we cannot continue to extend these laws to shorter and shorter distances. If this proves to be true, it may lead to important changes in fundamental concepts of space and time, and perhaps probability. This study requires a large momentum transfer in the electron-scattering process, which implies investigations at large scattering angles where the cross-sections are very small. Hence, the availability of high electron current in the proposed accelerator would be quite essential to the success of the experiment. The second experiment involves the study of electromagnetic pair production of weakly interacting particles. Two examples are now know, the electron and the μ meson, which can be produced only by means of electrons or photons and only indirectly by protons. There may well be other particles in this class, and the systematic search for such particles may be an important application of the proposed accelerator.

FIGURE 11. - Center of mass energies and thresholds for various processes

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In the above discussion many advantages of high-energy electrons as bombarding particles in physics research have been pointed out. From this it is clear that the linear accelerator is the only machine available which can accelerate electrons above a level of 8 to 10 Bev. This is the maximum practical energy range of electron synchrotrons, because of radiation considerations. In addition to making higher energies available, the linear accelerator also has the advantage of providing an external electron beam of high intensity and very small angular divergence. These characteristics greatly increase the number and variety of experiments which can be undertaken and the general utility of the machine.*

Finally, it should be emphasized that throughout the world there are now only five accelerators being designed or constructed with energies greater than 10 Bev. We have listed these machines separately in Fig. 12 together with their types of accelerated particle, maximum energies, currents, and beam powers. An examination of this chart

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*A further example of the versatility of the linear electron accelerator is demonstrated by the colliding beams experiment which will be performed with the Stanford Mark III accelerator. This project is a combined Princeton-Stanford effort and is sponsored jointly by ONR and AEC. In this experiment, 500-Mev electrons from the Mark III are caused to circulate in two tangent magnetic storage rings. The direction of rotation in the rings is the same so that the beams can collide at the point of tangency. The available center-of-mass energy in this collision is 1 Bev. To obtain the same equivalent energy with a single electron accelerator bombarding a fixed electron target would require an incident energy of 1,000 Bev. The expected circulating current of 1 ampere in each beam will result in roughly 2 to 3 collisions per second. Experimental information from scattering of the colliding electrons will be used to check the short-range validity of quantum electrodynamics. Other contemplated experiments make use of a stretched-out gamma-ray beam created by a continuously circulating electron beam in a single storage ring.

ACCELERATORS BEING DESIGNED OR UNDER CONSTRUCTION

ACCELERATORS BEING DESIGNED OR UNDER CONSTRUCTION WITH ENERGIES GREATER THAN 10 BEV

ACCELERATOR	TYPE	PARTICLE ACCELERATED	MAX. BEAM ENERGY (BEV)	AVERAGE BEAM CURRENT (MICRO-AMPERES)	AVERAGE BEAM POWER (WATTS)	STATUS
ANL	C.G. SYNCHROTRON	PROTON	12.5	.0028	35	DESIGN
BNL	A.G. SYNCHROTRON	PROTON	25	.002	50	CONSTRUCTION
CERN	A.G. SYNCHROTRON	PROTON	25	.002	50	CONSTRUCTION
USSR	A.G. SYNCHROTRON	PROTON	50	.001	50	DESIGN
"M"	LINEAR	ELECTRON	20 (STAGE I) 40 (STAGE II)	30 60	600,000 2,400,000	DESIGN

FIGURE 12. - List of accelerators with energies greater than 10 Bev

causes two facts to stand out quite clearly. First, it may be noted that the proposed Project M accelerator is the only one of these 5 high-energy machines which provides electrons for research purposes; all the others accelerate protons. Secondly, the beam power available from the Project M machine is higher than that from the other accelerators by a factor greater than 10,000.

B. General Description of Proposed Accelerator

Certain technical specifications of the proposed accelerator have been changed since our original proposal in 1957. The major revisions are as follows:

1. In line with the recommendation of the Subcommittee on High-Energy Accelerators of the President's Science Advisory Committee, we have decreased the number of klystron amplifiers initially connected to the accelerator from 480 to 240. This will result in an electron energy of 10 Bev, in contrast to the previously stated 15 Bev for the conservative operation at 6 megawatts per klystron. The length of the accelerator will remain the same as originally proposed so that the very important concept of energy "expandability" by connecting additional power sources has been preserved.

2. The maximum peak power output per klystron has been increased from 22 to 24 megawatts and the pulse length from 2 to 2.5 microseconds. These changes will result in greater potential electron energy and improved electron beam duty cycle.

3. The klystrons are being designed to provide the maximum power of 24 megawatts and pulse length of 2.5 microseconds at 360 rather than 180 pulses per second, as called for in our original proposal. The combined effect of greater pulse length and higher repetition rate is an increase of maximum beam duty cycle by a factor of 3 at the highest energy level.

4. The klystron modulators and power supplies will be constructed at higher ratings to conform with the new maximum klystron performance figures. In the initial proposal the modulator power figures were based upon 6 megawatts peak power per klystron, 360 pulses per second and 2 microseconds pulse length. This has caused the total klystron power consumption to be increased from 9.9 megawatts to 20.8 megawatts maximum.

5. The maximum power consumption for all other purposes including the target area has been increased from 17.2 to 38.4 megawatts.

These changes are primarily directed toward the idea of preserving expandability in energy by providing initially sufficient power capability per klystron to handle the ultimate requirements. This means that energy expansion to the ultimate 45 Bev level would later be possible by connecting additional power components identical in design and ratings to the original set of components, rather than by a complete replacement of the original equipment. It also means that it will be possible to obtain energies as high as 20 Bev with the initial complement of klystrons should the increased klystron attrition rate be justified by the scientific urgency of a particular experiment.

There are a large number of degrees of freedom in the design of a linear electron accelerator which make it possible to obtain a given

energy in many different ways. The initial parameters of the proposed accelerator were chosen such that a minimum energy of 10 Bev could be easily obtained. This energy is above all known particle-production thresholds, and is also above the practical limit of the circular electron synchrotrons. In addition, this initial energy would permit the investigation of nuclear and particle structure at distances as small as the nuclear Compton wavelength.

The energy of electrons from a linear accelerator is proportional to the square-root of the product of the total radiofrequency power and the accelerator length. Therefore, the most economical design results when the power-proportional and length-proportional costs are made equal. A study was made of the various cost factors, taking into account both the initial construction costs and operational costs over a 10-year period. As a result of this study we chose 2 miles as the most economical accelerator length in the energy range of 10 to 20 Bev. This results in a machine which has a comparatively low electric-field gradient (1 Mev per foot compared to 3.2 Mev per foot for the Stanford Mark III accelerator). Thus, the design we have chosen is not only the most economical based upon currently available microwave power sources, but its conservative voltage gradient will also permit later increase in electron energy by a factor of 4 or more without encountering electric-field limitations. This increase in energy can be accomplished simply by adding additional power sources in already existing "sockets" without other modification of the machine. Indeed, the design is such that the energy increase can be obtained with little or no disruption in operating schedule. Our estimates show that increasing the electron energy from the initial range of 10 to 20 Bev to the higher range of

20 to 45 Bev can be made at a small fraction of the cost of a new machine at the higher energy level. Our proposal is concerned only with the initial complement of power sources necessary to obtain the 10-to-20 Bev energy range. Any future decision to increase the available energy level must be based upon the requirements of physical research and the power-cost factors in effect at that time. However, we feel that it is extremely important that the ability to expand to the 45-Bev energy level should be emphasized both in the basic concept and in the actual design of the proposed machine.

In any energy range, the design of the proposed accelerator will permit variation of energy from maximum down to 1 Bev without appreciable loss in beam intensity. This is important because it will permit the machine to overlap the energy range of other accelerators of the same type, including the Stanford Mark III accelerator, the Orsay Accelerator (now under construction in France), and the Russian machine at Kharkov. This will permit broad experimental coverage and the extension of cross-section curves to both high and low energies without gaps. To operate over this extended energy range at high intensity will require the use of auxiliary electron guns along the accelerator length. Present plans are to utilize six guns, with hollow cathodes, equally spaced along the accelerator length. In addition to permitting high currents over all energies, the existence of these guns will allow as many as 6 simultaneous beams integrally related in energy. Thus, it will be possible to carry on several experiments at different energies at the same time, should this be desired. This is another example of the flexibility of the linear accelerator in physics research.

The accelerator proper will consist of a disk-loaded cylindrical waveguide, as shown in Fig. 13, supplied with microwave power at a frequency of 2856 Mc/sec. The accelerator will be made in sections 10 feet long, and each of these sections will be independently fed with power through a suitable S-band waveguide and waveguide-to-accelerator coupler. A total of 960 sections will comprise the entire accelerator. The accelerator will be supplied with power by 240 klystron amplifiers each capable of producing up to 24 megawatts of peak power at 360 pulses per second and 2.5 microseconds pulse length. The power output from each klystron will be divided 4 ways and will be used to supply power to 4 successive 10-foot accelerator sections. With this initial complement of tubes, each operating at the very conservative level of 6 megawatts, the accelerator will be able to supply electrons with energies of 10 Bev. The energy can be increased from 10 to 20 Bev by increasing the power output from each klystron from 6 to 24 megawatts. Operation with a complement of 240 tubes will be referred to as Stage I.

To operate at energy levels above 20 Bev it will be necessary to increase the number of klystrons and their related modulators and power supplies along the accelerator length. It will be possible to connect a maximum of 960 klystrons to the accelerator, in which case each klystron will feed a single 10-foot accelerator section. This condition of operation will be referred to as Stage II. With 960 klystrons each producing 24 megawatts of peak power, an electron energy of about 45 Bev should be obtained. Klystron connections to the accelerator in Stage I and Stage II are shown in Fig. 14.

The only difference between Stage I and Stage II is in the number of power sources connected to the accelerator. There is no distinction

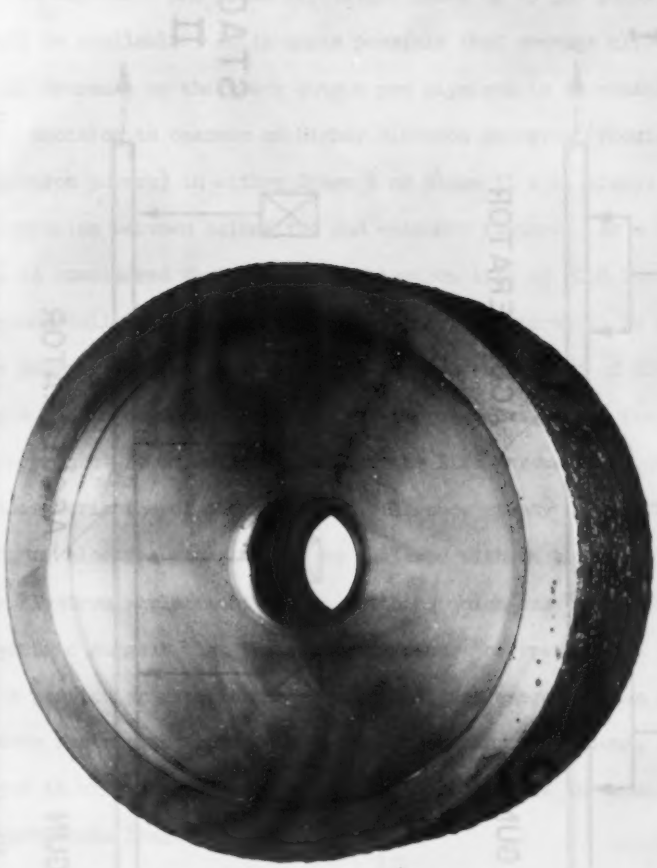

FIGURE 13. - Photograph of disk-loaded cylindrical waveguide

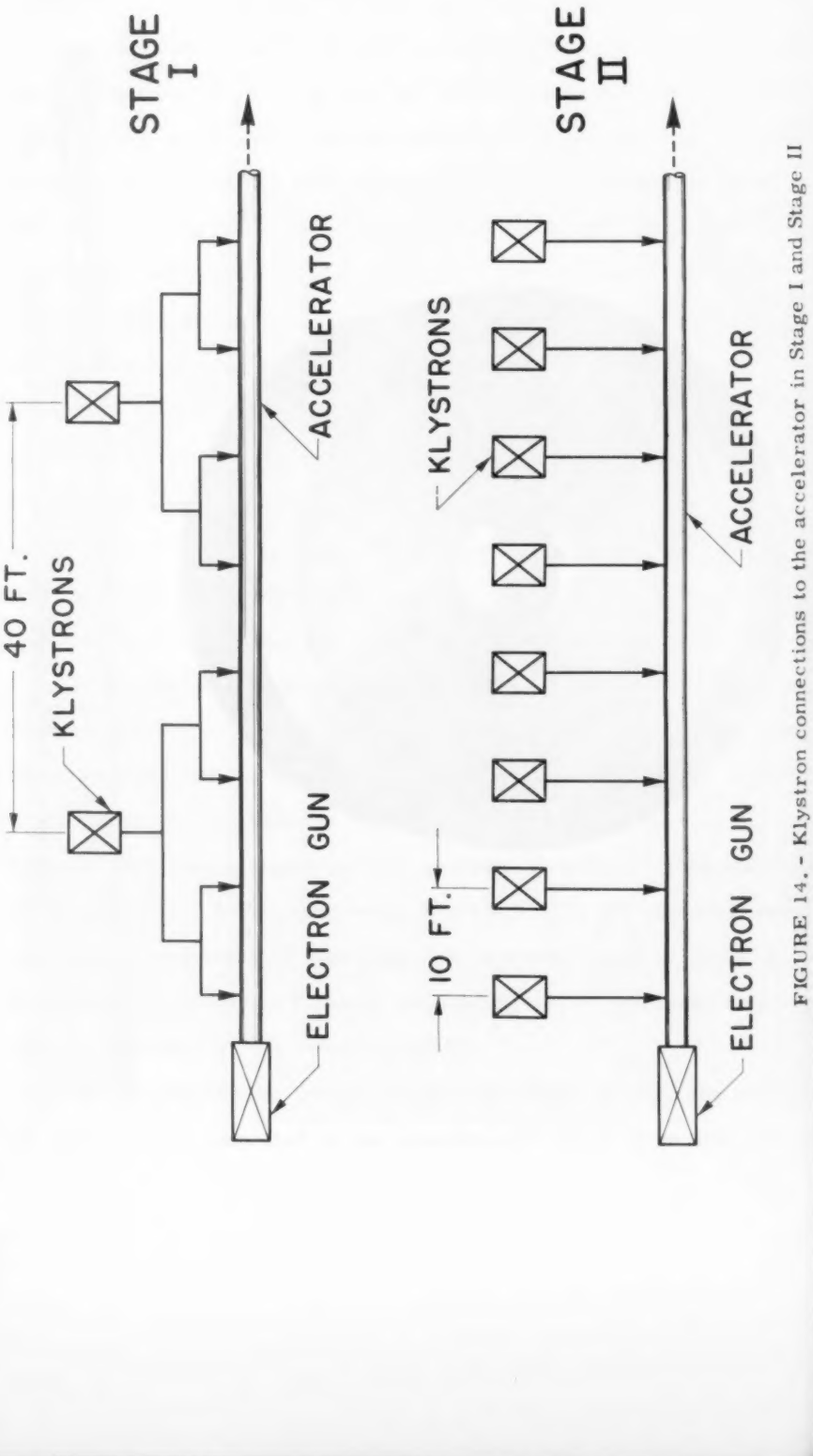

FIGURE 14. - Klystron connections to the accelerator in Stage I and Stage II

on the basis of maximum power output per klystron or maximum pulse repetition rate. In each case, power outputs ranging from 6 megawatts to 24 megawatts and pulse repetition rates up to 360 pulses per second will be available. It is quite possible that average klystron life will decrease as the power output per klystron is increased. Therefore, the decision to operate at higher electron energies (requiring higher klystron powers) in either Stage I or Stage II will always involve a compromise between scientific and economic factors. As a rough rule, it is considered that an average klystron life of 2000 hours is economically tenable. Using this criterion, operation is permissible at power levels which will result in an average life of 2000 hours or more. With expected technological improvements during the course of the project it is anticipated that the life versus power-output characteristics of the klystrons will show steady improvement, so that higher electron energies can be achieved without appreciable increase in klystron replacement costs. Nothing which has been said here is meant to suggest that the klystrons cannot be operated at higher levels for particular experiments requiring higher energies than normal. The above restriction refers to average operating conditions, and in any case it will probably serve only as a rough guide in establishing appropriate limits.

A summary of the tentative specifications for the proposed accelerator is given in Table II.

The accelerator and its related equipment will be situated in two parallel underground tunnels. The accelerator proper will be located in one of the tunnels which is 10 feet wide and 13 feet high. The

FIGURE 14. - Klystron connections to the accelerator in Stage I and Stage II

TABLE II

Summary of Tentative Specifications for the Proposed Accelerator

	Stage I	Stage II	Note*
Accelerator length	10,000 feet	10,000 feet	
Length between feeds	10 feet	10 feet	
Number of accelerator sections	960	960	
Number of klystrons	240	960	
Peak power per klystron	6-24 Mw	6-24 Mw	
Pulse repetition rate	1-360 p.p.s.	1-360 p.p.s	1
R. F. pulse length	2.5 μsec	2.5 μsec	2
Average input power klystron power supplies	20.9 Mw	83.6 Mw	3
other demands (including target area)	38.4 Mw	43.4 Mw	
Total Power Demand	59.3 Mw	127.0 Mw	
Electron energy, unloaded	12-24 Bev	24-48 Bev	4
Electron energy, loaded	11-22 Bev	22-44 Bev	4
Peak beam current	25-50 ma	50-100 ma	5
Average beam current	15-30 μa	30-60 μa	5
Average beam power	0.3-0.6 Mw	1.2-2.4 Mw	5
Filling time	0.83 μsec	0.83 μsec	
Electron beam pulse length	0.01-2.1 μsec	0.01-2.1 μsec	6
Electron beam energy spread (max.)	± 0.5%	± 0.5%	7
No. of simultaneous electron beams (max.)	6	6	
Operating frequency	2856 mc/sec	2856 mc/sec	
Klystron life (min.)	2000 hrs.	2000 hrs.	
Operating schedule	24 hrs/day	24 hrs/day	8

*For the notes referred to in the last column, see next page.

NOTES FOR TABLE II

1. Electron beam pulse repetition rate will be adjustable in multiples and sub-multiples of 60 p.p.s. It will also be possible to turn on the beam for a predetermined number of pulses. The pulse repetition rate of the klystron modulators will be adjustable in multiples of 60 p.p.s. between 60 and 360 p.p.s. Electron beam pulse rates below 60 p.p.s. will be obtained by appropriate adjustment of the p.p.r. of the r.f. drive and the electron gun.

2. This is the length of the flat-top region of the pulse.

3. Total average input power to modulator power supplies is based upon 74 kw output power per modulator and 85% combined modulator-power supply efficiency.

4. In both Stages I and II the accelerator will be capable of supplying electrons with energies as low as 1 Bev without sacrifice of maximum current.

5. At design loading and maximum electron pulse length. The actual currents obtained during operation are expected to be lower. However, for very short pulse lengths, even higher currents should be obtainable.

6. These are extreme limits of beam pulse length. Longer pulse than usual is provided to allow injection when accelerator sections are partially filled, thus reducing transient energy spread.

7. After transient period.

8. Design objective.

klystrons, modulators, vacuum pumps, and wiring will be located in the second tunnel which is 24 feet wide and 22 feet high. In this second tunnel, space will be provided for two-way traffic transporting personnel and equipment. The accelerator tunnel can be entered only when the electron beam is turned off, but the klystron tunnel can be continuously occupied. The two tunnels will be separated by 35 feet of earth which will serve as radiation shielding. There will be a lateral waveguide feed between the tunnels every 10 feet and a 5-foot by 9-foot lateral tunnel every 250 feet for personnel access. A schematic view of the accelerator site and the tunnels is shown in Fig. 15.

Although the accelerator is completely underground except in the target area, a width of 1000 feet and a length of 10,000 feet of overlying terrain is being reserved. The area included amounts to 230 acres. The beam-switching and target facilities increase the total length of the land reservation to 12,600 feet and the total area to 380 acres.

The large area available for experimental purposes greatly enhances the potential utility of the accelerator. It is sufficiently large that any foreseeable experiment can be performed. The electron beam emerging from the accelerator will have a diameter of about 1/4 inch and an angular divergence of only 10^{-5} radians. This excellent geometrical quality of the beam will permit a wide dispersal of the experimental equipment. This is of great advantage since the machine is expected to attract a large number of scientific workers and a diversified group of experiments will be programmed. Multiple experimental stations are especially useful since the equipment required

to handle the high-energy beam will be quite massive and relatively immobile. An extended set-up time will be necessary in many cases. The ability to transmit an intense high-quality beam to multiple experimental facilities will greatly increase the utility and productivity of the machine. A concommitant consideration is that the experimental areas can be sufficiently separated and shielded from each other so that personnel can work at all the stations except the one actually receiving the electron beam.

A beam "switchyard" will be provided to conduct the beam to the various experimental areas. Plans have been made to provide 4 doubly-deflected beams plus an undeflected beam. The doubly-deflected beams are analyzed in energy and may be delivered to various experimental equipment along their paths.

Both thick-target and thin-target experiments are being contemplated. The thick-target experiments will be conducted inside a large (400 foot by 500 foot) shielded building. The three central beams will be piped into this building. Local shielding will be provided around each target facility in the building. The two outer beams will be reserved for thin-target experiments. In these experiments a double-focusing magnetic spectrometer will be mounted on a carriage that can be rotated in a horizontal plane around the target.

While it has been necessary to consider the various experiments which might be performed in order to provide for general planning of the experimental area, only a partial development of these plans will be carried out during the initial construction program. Certain equipment is needed to carry out the initial testing of the machine

FIGURE 15. - Schematic view of the accelerator site and the tunnels

and to permit research to start without a long delay while experimental facilities are being provided. On the other hand, it would be unwise to construct the complete installation until the experimental program begins to reveal the most promising areas of research and the most useful and sensitive techniques.

For these reasons, we plan to develop initially only the main target building and the left-hand double-deflecting magnet system.

C. Present Status of Component Development

Since 1954 an accelerator development program sponsored by the Atomic Energy Commission has been under way at Stanford. The main work of this program has been the detailed testing and improvement of the various components associated with linear electron accelerators. Efforts have been made to develop components of increased efficiency, reliability, and to incorporate design features contributing to greater ease of manufacture, operation, and maintenance. A complete account of this work has been given in the Status Reports of this Project and in various Technical Reports prepared by staff members. Space does not permit a detailed account of the present status of the large number of related components. However, we would like to describe briefly the present position with respect to two of the most important components, the disk-loaded accelerator waveguide and the klystron amplifier.

All of the Stanford accelerators built to date have operated in the $\pi/2$ mode; i.e., the disks are spaced at intervals of one-quarter guide wavelength. Recent measurements have shown that the shunt impedance of these structures can be improved about 25 per cent by designing the accelerator to operate in the $2\pi/3$ mode; i.e., with a

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disk spacing equal to one-third of a guide wavelength. The energy of electrons produced in a linear accelerator is proportional to the product of the total radio frequency power, the total accelerator length, and the shunt impedance per unit length. Thus, for fixed length, shunt impedance and power have equal influence upon energy and may be traded on an equal basis. Alternately, for fixed power input the electron energy will be increased by the square root of the factor of improvement in shunt impedance. Thus, the $2\pi/3$ mode promises to result in better utilization of the available radiofrequency power in accelerating electrons to high energies. It is our intention to operate the proposed accelerator in this mode provided that further tests corroborate the optimistic results so far obtained.

Although new fabrication techniques may be devised before the proposed accelerator is constructed, our present intention is to fabricate the accelerator by an electroforming technique which has been developed at Stanford Univesity. In this method, the copper disks are stacked on a mandrel and are separated the proper interval by means of aluminum spacers. An outer wall of copper is electroformed over the stacked disks and spacers. After the electroforming procedure has been completed, the aluminum spacers are removed from the assembly by being etched away in a bath of sodium hydroxide. The remaining structure is an all-copper disk-loaded tube in which the copper disks are securely bonded to the walls of the tube. This process results in the most precise, uniform, dimensionally stable and the lowest-loss structure which has yet been obtained by any method. Tests have shown that the completed structure can be used to

accelerate electrons with excellent results. Thus far, these tubes have been fabricated in one piece units with a maximum length of $5\frac{1}{2}$ feet. The present limit is imposed by the size of the existing electroforming facilities. Although it is possible to braze two of these units together to form the desired 10-foot sections, it is our intention to electroform single 10-foot sections for the proposed accelerator.

As already mentioned, the proposed accelerator would require initially 240 klystron amplifiers each producing 6 to 24 megawatts of peak power. We have had considerable experience with a tube of our own design which satisfies these requirements over the past 10 years in conjunction with operation of the Stanford Mark II, III, and IV accelerators. A photograph of this tube is shown in Fig. 16. A model which is more suitable for quantity production is now being designed. Design improvements are also being incorporated in the new version which should result in increased gain and efficiency and an improvement in overall performance characteristics. The new tube will be sealed off independent of a vacuum system, in contrast to the older version which is continuously pumped.

D. Schedule of Construction

There are approximately 25 scientific personnel who are now available at Stanford to work on the proposed accelerator construction program should it be authorized at this time. The majority of these people have had considerable previous experience with high-energy accelerators of this type and will form the nucleus around which the project can grow.

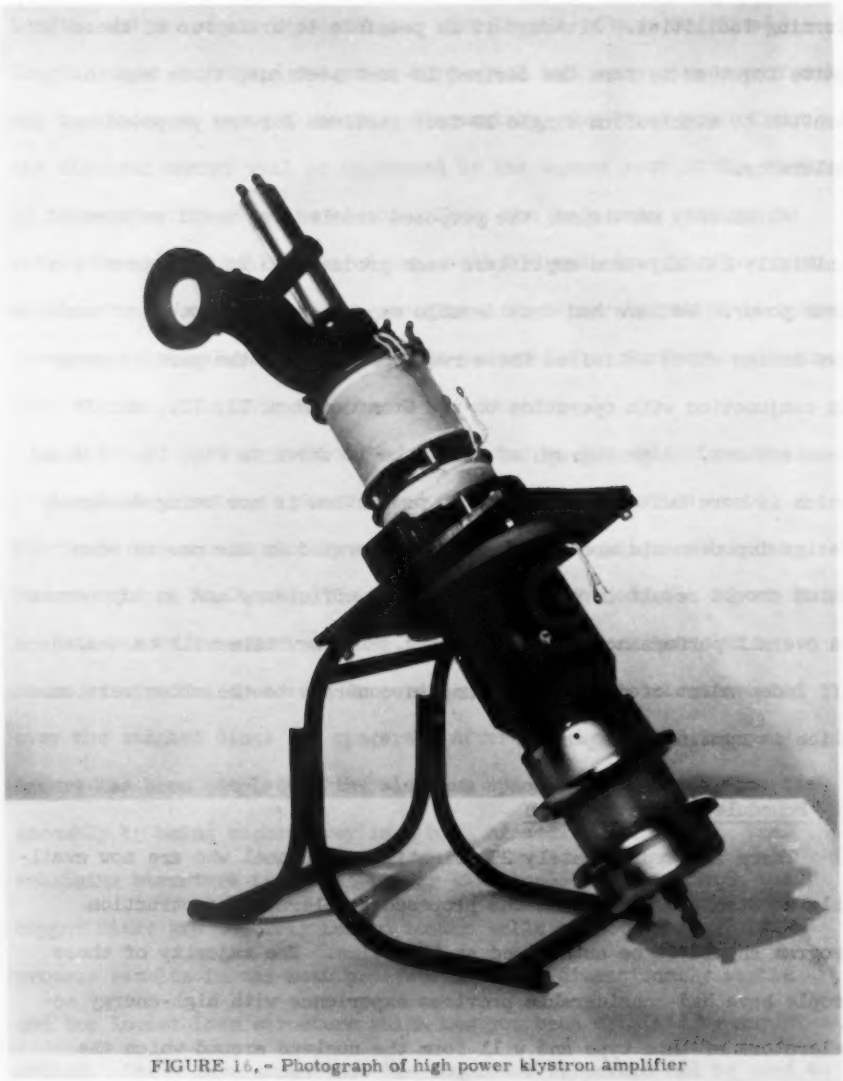

FIGURE 16. - Photograph of high power klystron amplifier

During the first six months the above group will carry out basic planning and the initial phases of design. New scientific personnel will be added during this period and integrated into the existing organization. Design of the general laboratories and shops will be accomplished during the first half of the first year with the assistance of outside architectural firms.

The entire schedule of construction is shown in Fig. 17. A total period of 6 years will be required from the date of authorization until the machine is ready to undertake physics research.

Construction of the laboratories and shops will start during the latter half of the first year and will take place in two phases so that the first group of facilities will be available early in the second year. The remaining construction will spread over into the third year.

Tunnel design and site development will start as early as detailed plans can be made available during the first year, and construction will be completed by the end of the third year.

Klystron, accelerator, vacuum component, power component, and instrumentation design will also be begun during the latter half of the first year or early in the second year; and, after a suitable period of testing and reliability studies, construction will be completed during the fourth and fifth years.

A very important part of the construction program is the assembly and test of a short test section of the machine. This test section will provide advance engineering and operational information which will be very helpful in making the final machine more reliable, more easily operated and maintained, and of greater overall utility.

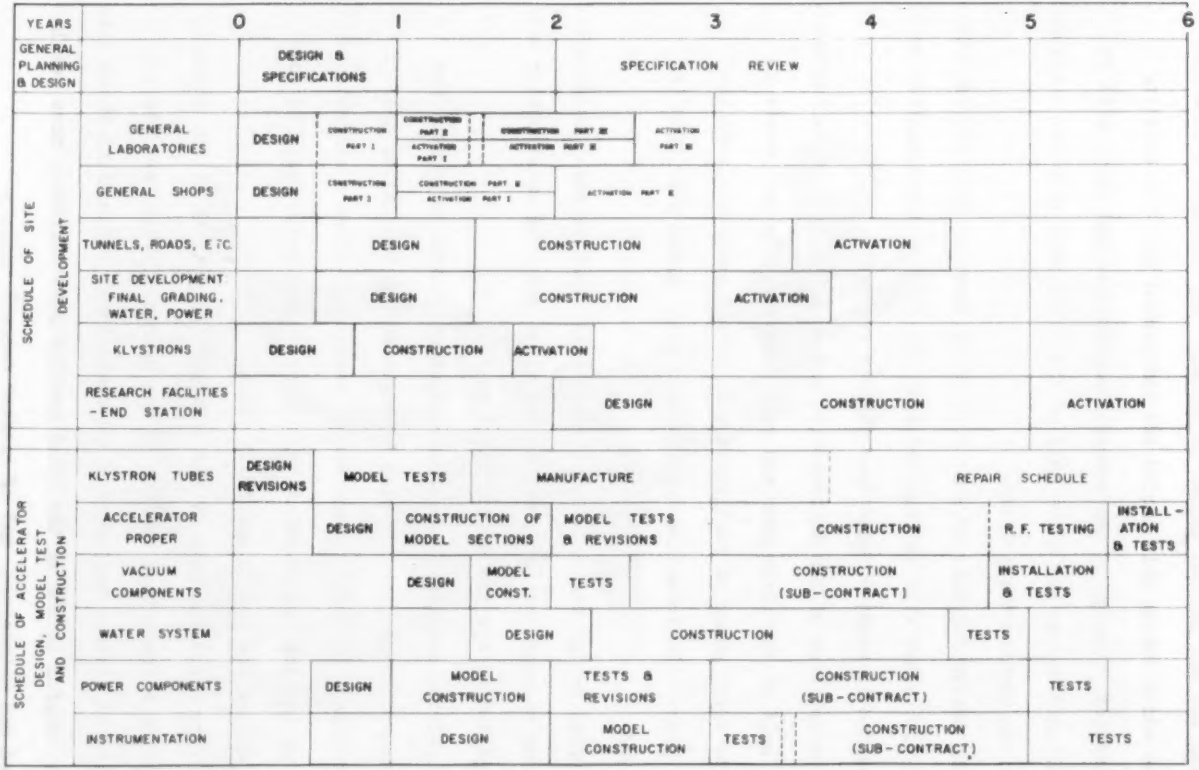

FIGURE 17. - Schedule of construction

The last half of the fifth year will be devoted to installation of the major components to constitute the complete accelerator installation. Most of the final (sixth) year will be used for testing of the machine, for establishing operational and maintenance procedures, and for general "shakedown" purposes.

V. COST OF CONSTRUCTION

The proposal which Stanford University presented to the Government for construction and operation of a two-mile-long linear electron accelerator in the spring of 1957 contained estimates of construction cost as well as of the annual cost of operations for research. The operating costs are discussed in the next section of this statement. The original estimating work was done during the period November, 1956, to April, 1957. The estimating work was divided into two categories which were handled in different ways. One category concerned the general topic of tunnels, buildings and grounds. The project's requirements with respect to these items were established generally by the technical staff involved in the proposal, and these requirements were then discussed with members of the Utah Construction Company and Bechtel Corporation staffs whose services were generously donated by their firms for the purpose. Both firms assisted us materially in arriving at reasonable solutions to our problems and in estimating the costs of the plant. The estimates for this category, which appeared in our proposal, were provided by the Utah Construction Company.

The other category concerned the components of the accelerator and of the equipment needed for their fabrication and testing. The description and specification of these components was done by a number of committees of our staff, each having responsibility for a system or coherent group of components, such as, for example, power facilities, klystrons, the accelerator structure itself, shielding, control and instrumentation, etc. There was much cross-checking between the committees to assure that no substantial items had been omitted or incorrectly described. The

work of these committees began approximately a year before the proposal was printed. Each committee then undertook to estimate the cost of the materials, the labor, and equipment required by its specifications. In general, these people had had a role in the development and construction of the Mark II, III, and IV accelerators at Stanford, and thus had some qualifying experience. Current material prices were available and were used. The labor rates used were predicted on the basis of experience in our area as of July, 1959. It should be noted that with respect to methods of fabrication the committees were conservative and used methods then known and used by us. Even though it was obvious that one should be able to expect unit savings when producing, by quantity production methods, an accelerator about fifty times as long as the Mark III, we were not then able to determine how such methods might be applicable and what savings would in fact result. The work accordingly was estimated on the basis of what could more properly be called "job lots" than quantity production. The introduction to our construction cost estimate section in the proposal made this fact plain.

The cost estimate in the 1957 proposal was given as $78,000,000, but it was pointed out that this was not actually the full cost, since several items had been omitted. One of these was reimbursement to the University for indirect costs. This item was not included because it could not then be determined. Too many factors, which would establish it, would be matters of agreement between the sponsoring Government agency and the University, and at that time it was completely unknown if the project would be sponsored at all. On the other hand, while proper provision for indirect costs, it was noted, would ultimately be important to the University, which could not afford to undertake such a project

unless all actual costs could be recaptured, the indirect costs themselves could not be a significant fraction of the total.

The second item which was not included was an estimate of escalation for the accelerator and associated equipment. We noted that we did not feel that we were competent to estimate escalation. However, as we stated, the Utah estimate of plant costs did include an allowance for escalation (approximately $2,000,000).

The third item which our estimate did not include was an allowance for contingency. This was in line with our experience to that time with the government agencies that sponsored research and development work in our Laboratories; we had been instructed not to include contingency items in our proposals.

In June of 1958 the AEC asked Brobeck Associates to review our proposal and our cost estimates. The instructions to Brobeck permitted them not only to challenge our estimates, which we appreciated, but to fill in the missing items and to add to the construction costs an item which we had deferred to our research operations budget, an initial complement of research equipment to be used with the accelerator. Brobeck suggested without any guidance from Stanford that inclusion of reimbursement of indirect costs would raise the Stanford estimate from $78,000,000 to $79,500,000. For the purposes of this statement, therefore, we shall assume that the Stanford estimate has been adjusted to $80,000,000 from $78,000,000 to include both direct and indirect costs.

With respect to the costs which we have presented in the proposal, Brobeck added $8,000,000. He and his consultants, who included Kaiser Engineering for the review of plant work, concluded with respect to design, fabrication and testing of the accelerator components and systems that we should have allowed $3,000,000 more. They also concluded that

we should have provided more space in tunnels and in some of the buildings, and that we should have allowed for higher standards of construction in the tunnels. They therefore estimated $5,000,000 more for the tunnels.

Having made this correction, the Brobeck Survey then added costs which were not included in our estimates as noted above. The first of these was an estimate of $4,000,000 for the initial complement of research equipment to be used for the completed accelerator. The second was an allowance of $13,000,000 for escalation, and the third $11,000,000 for contingency. The total, therefore, according to Brobeck, became $116,000,000.

During this past spring, we have engaged in detailed discussions of the cost estimates with representatives of the Atomic Energy Commission, and these have led to the figures in the Project Data Sheet which has been submitted to this Committee. It will be noted that the costs are currently estimated at $105,000,000 for construction items and $18,000,000 for research and development work. We would like to point out that "Research and Development" is not particularly descriptive of the purpose of the $18,000,000. It is in fact true that without advance in technology or improvement of components the proposed accelerator could still be built. No research or development is needed. On the other hand, it is equally apparent that it would not be sensible to accept the same standards of reliability, economy and convenience for operating a two-mile-long accelerator around the clock throughout the entire year as one is willing to accept in the case of what might be considered a prototype of the big machine, namely the Mark III accelerator, which is 220 feet long, is operated on approximately a half-time schedule and involves an

annual operating budget of about $1,000,000 a year. In terms of getting the greatest return from the approximately $100 million investment in the proposed machine, the expenditure of $18 million is believed to be judicious. This sum will be used to improve the components and systems beyond the stage in which they now exist so as to assure optimum performance, minimum operating costs, maximum reliability, and thereby provide maximum time for research.

The Brobeck revision of the Stanford estimates was accepted as the starting point for our discussion with the Commission. As previously explained, this estimate was $116,000,000, while the cost figures which are presented to this committee now aggregate $123,000,000. There would not seem to be any point in repeating in this text the detailed estimates which are summarized in the Project Data Sheet, but it may be interesting to identify and discuss to some extent the changes which have resulted in the over-all increase of $7,000,000.

It is possible to summarize briefly the effects of the discussions with AEC representatives based upon the Brobeck estimates. These can be shown by the following simple table (next page).

Title	Brobeck	Construction Per Project Data Sheet	Components Improvements (R and D Per Project Data Sheet)	Increase or Decrease
Engineering, Design, Test and Inspection	$ 18 x 10^6	$ 8	$ 18	+$ 8
Land Improvements, Tunnels, Buildings, Utilities, etc.	25	41	-	+ 16
Accelerator System	39	24	-	- 15
Equipment	10	10	-	--
Escalation	13	9	-	- 4
Contingency	11	13	-	+ 2
	$ 116	$105	$ 18	+$ 7

The major changes are quite apparent. Whereas Brobeck had allowed $18,000,000 for all design, inspection and test work including improvements in the components, the AEC attributed $8,000,000 to construction, design and inspection work, and increased the amount available for components improvement to $18,000,000, a net increase of $8,000,000. In essence, they agreed with us that this additional investment during the design period would repay itself in ten years or less of operations. It will be noticed that the totals for the next two categories have changed in almost equally offsetting amounts. This is a matter of change of definition of which of the two categories is more appropriate to record certain costs. The escalation factor was too great and the contingency fac-

tor too low in the Brobeck estimate, in the opinion of the AEC representatives.

The above is a summary of the major points. There were, of course, many minor adjustments, a few of which it may be worth-while to recall. For example, the cost of procuring klystrons was reduced in accordance with the decision that fewer klystrons would be needed in the initial operations. Also, at the time the Stanford proposal was written it was not prudent to assume that klystrons for the accelerator could be purchased commercially, and, hence, a klystron production facility was contemplated. By the time of the AEC meetings, however, it was clear that a safe commercial supply could be predicted. As a result, the size of the plant for klystron work and the amount of equipment to be housed in it were decreased, reducing it from a production facility to a development laboratory.

Minor adjustments were also made with respect to building space. The allocation for klystron work and for accelerator-test sections was reduced by ten thousand square feet. On the other hand, we were persuaded by the AEC that it would be wise to add an equivalent amount for additional office space for staff, having particularly in mind the fact that the accelerator facility will attract visiting physicists, whose accomodations must be provided. In addition, we were convinced that, by reason of the distance between the project site and the main campus buildings and various protective services, that it would be well to add almost ten thousand square feet for an auditorium, a cafeteria, a fire station, and guard houses.

The unit costs of all buildings were increased over the Brobeck estimates on the basis of AEC's experience during the year since the Brobeck estimate was made.

VI. OPERATING COSTS

A. Stanford 1957 Estimates

The 1957 Stanford Proposal contained a statement and an estimate concerning the annual operating costs after completion of the machine. This material was prepared by staff members who had direct experience with the operational requirements and costs of the Mark III accelerator, and who were moreover aware of the experience in other laboratories with high-energy particle accelerators, either by occasional participation in research programs of these laboratories or by consultation during preparation of the proposal. As far as the costs of maintaining a linear electron accelerator and operating it in physics research were concerned, there was no experience elsewhere comparable to that available in our laboratories. On the other hand, other laboratories, such as UCRL, Brookhaven and Argonne, had longer experience with respect to the needs of high-energy research programs, particularly in the development of research equipment and treatment of shielding problems. The staffs of these laboratories were most helpful to us in providing information useful in predicting costs of equipping for research during the operational period.

As was true in the construction cost estimate, the operating cost estimate did not cover indirect costs, contingency or escalation. The basic costs of annual operation included 6 million dollars for running and maintaining the accelerator, 2.5 million dollars for the research program, and 1.5 million dollars for administration and general services for the aforementioned functions. The sum of the three items was 10 million dollars a year. In addition to these, we included

estimates of construction work of two types. The first was $2.5 million dollars for the construction of large research equipment, such as research magnets or bubble chambers. The second was $1.5 million dollars for capital improvements of the machine, shielding and buildings. It was pointed out that amounts of this kind for construction of equipment or plant changes were likely to be a recurring part of the annual operating budget. This was in acknowledgement of the general experience at Stanford, and at other high-energy physics laboratories in the country, that while it was impossible to predict in detail the specific equipment and related power sources or housing that would be needed for experiments some years in the future, it was certain that such needs would arise and would likely represent a third or more of the actual operating costs. The total budget, therefore, for operating and equipping the accelerator for research was estimated at $14 million dollars.

B. Brobeck Analysis.

The Brobeck Survey of 1958 estimated these same costs, including indirect expense, at about 2 million dollars more. There was one major difference between the Stanford and the Brobeck assumptions which accounts for half of the difference. Stanford estimated that the number of physicists using the accelerator in research would be approximately 50, whereas Brobeck was of the opinion that something like 90 could be accommodated. The cost of the 40 additional physicists, plus supporting staff and other related costs, accounts for much of the difference between the Stanford and Brobeck figures. It may be that we underestimated somewhat the number of physicists for whom the accelerator could serve as a research tool, but it is our opinion that Brobeck's estimate is too

liberal. In any case, it is difficult to be precise about costs so far in advance. We have discussed the matter with the Atomic Energy Commission and are in agreement that $15 million per year is a reasonable indication of the operating budget, and that it should be noted now that requests for capital additions are probable.

It is our intention, and an important part of the specifications for construction of the accelerator, that when completed it shall be operated steadily around the clock and throughout the year. This fact, which was recognized in the construction and operating cost estimates, will help to derive the maximum returns of new research information on the large investment which is proposed for the machine and its housing services.

The construction cost estimates, as indicated in Section V of this statement, provide for an initial complement of research equipment to be built for use when the machine is operable. The cost of this equipment is $4 million. Nevertheless, it will become appropriate to begin a transition into the operating budget at some point not yet established, before the end of the construction phase. This will make it possible to plan in detail the research programs which are to be conducted in the early years of operation.

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VII. CONCLUSIONS

We believe that the scientific justification for the construction of this accelerator has been clearly established, as evidenced by the reports of the various panels and agencies and by the testimony presented to you by the representatives of the Atomic Energy Commission and by others in these hearings. Upon its completion the proposed machine would be comparable in energy to the highest energy accelerators in the United States and elsewhere but would be different from them in the kind of particle employed and in much greater beam intensity. Furthermore, a unique feature of the proposed linear electron accelerator is the possibility of increasing its energy without a large additional expenditure of funds. The maximum possible energy would be greater than that of any other machine, with the possible exception of one now under study in the U.S.S.R. At the highest energy, the machine would be capable of providing approximately two megawatts in its particle stream, a power 10,000 times higher than that of any other machine in existence or in the planning stages.

We thus believe that this accelerator would represent a major advance in the range of energy and intensity of particles available for physical research. The anticipated very high beam intensity would make it an abundant source of all known artificially produced particles and their anti-particles. The combination of high energy, well-collimated electron beam, and the high intensity will make possible an accelerated study of nuclear structure in much finer detail. In addition, the proposed accelerator will increase the available energy to the region where

study of the limitations of present theories of electrical interactions become feasible. These are some of the specific reasons which, we believe, justify the construction of such a powerful instrument for high-energy particle research.

We further believe that diversity of instruments is of great value in itself. Much of the wealth of fundamental information covered in recent years is as yet imperfectly understood, and it is, therefore, not possible to establish a long-term specific program of research for any multi-Bev machine which is still in the planning stage. It follows, therefore, that diversity among several installations - in kind of particle, energy, intensity, geometrical and other beam considerations - is of fundamental importance in assuring that the basic field of particle research will be comprehensively investigated.

Stanford University is in a unique position to exploit its long history of contribution to research, development, construction, and use of accelerators of the proposed type. The construction of linear accelerators is based principally upon microwave techniques, a field which has been a speciality in the Physics and Engineering Departments of the University, stemming from the discovery of the rhumbatron by Hansen, the invention of the klystron by the Varian brothers, and development of the multi-megawatt klystron by members of the Hansen Laboratories staff. Some of these techniques, which are required for a successful construction of the proposed accelerator, have not yet been duplicated outside of the laboratories of Stanford University. Although we expect that much of the fundamental knowledge being developed in these laboratories will eventually spread to industry and elsewhere,

at the present time the combination of skills available at Stanford make the University the logical place to undertake the construction of the proposed large accelerator.

We have considered the precise location of the accelerator very carefully and have evaluated several hypothetical sites. Because of the requirement of shielding, it is necessary to cover the accelerator with a substantial thickness of earth or concrete. This is most easily done by the expedient of using tunnels to house the machine. It is fortunate that a suitable site exists at Stanford, providing two miles for the accelerator and merging into a flat 200-acre site where research with particles can be conveniently conducted. The proximity of this site (five minutes by car from the heart of the University) assures the important requirement of close contact between the staff of the project, the faculty and the students of the University. If such a facility were to exist in relative isolation, there would be a strong and justifiable tendency to create around the project many of the specialized departments which already exist in the University. The diverse requirements and multi-disciplinary character of modern research make this inevitable. This development is expensive in time, plant, and personnel and need not be undertaken under the circumstances envisioned in our proposal. We believe that the ultimate research program for this machine must be integrated with the broader and more diverse activities in research and education that characterize a modern university. To repeat, we do not propose to create a new site which, in time, would expand and support programs other than those connected with physics research with the accelerator, but we suggest rather the incorporation of this facility

within the framework of an established and expanding university program in teaching and research. Recognizing that the proposed project is an educational and research activity, Stanford University has offered the use of 400 acres of its academic reserve for this project without cost to the Government.

Finally, we believe it is not immodest to say that Stanford has, at the present time, the largest and most experienced single group of men who are qualified to build a machine of the proposed type. The essential specialized knowledge, experience in design, construction and operation, and enthusiasm are all present at this University in a unique degree.

Dr. GINZTON. In that case, Mr. Chairman, I would like to go over the more important points of my presentation orally, without direct reference to the document, except on occasion.

Mr. Chairman and gentlemen of the Congress, I would like to first of all summarize what it is we wish to build. You have heard our proposal described today by the gentlemen from AEC and Dr. Haworth. Nonetheless, just to be sure that you see that we are talking about the same thing, I would like to repeat the description of what it is we are proposing to build.

First of all, we are proposing to build an accelerator which will accelerate electrons rather than protons, making this a unique facility among machines above 10 Bev.

Second, under conservative operating conditions, this machine will produce an energy of 10 to 15 Bev. It can be expanded to an energy of 45 Bev. at a small fraction of the cost of a new machine.

Thirdly, the current—or intensity—provided by this machine will be approximately 10,000 times higher than any other machine proposed in the same energy range. As Dr. Haworth already said, it will provide an extremely accurate beam in space; for example, the beam would have a diameter—if it were to travel in free space—of approixmately 1 inch at a distance of 10,000 feet.

Next, gentlemen, I would like to give you a brief history of how this project came into being. If I may digress from the directly relevant testimony, I should like to give you a brief picture of what has been happening at Stanford since 1935, when this work began.

Representative PRICE. The work began on the accelerator project as far back as 1935?

Mr. GINZTON. Yes, sir. The work was begun at Stanford by Professor Hansen, a young brilliant physicist who began his research just prior to 1935. At that time it was already perfectly clear that high-energy research would be of tremendous value to science. Professor Hansen, being a member of a "poor" university, was in no position to buy expensive equipment, and wished to find a cheap way of generating high-energy electrons. He spent a great deal of time in search for solutions to this most difficult problem, but soon came upon an invention which he called the rhumbatron, which is an empty metallic container of this size [indicating a cigarette package] which could accelerate electrons to high energies.

Hansen's proposal did not get very far in 1935 because, at that time, there was not enough radio frequency power available to make such a device of any substantial practical interest. It was not until much later that people were able to invent methods of generating radio frequency power to make it possible to get substantial energy from a small container like this [indicating cigarette package].

Professor Hansen did not proceed with his ideas for accelerating electrons for two unrelated reasons. One reason was that at about the same time Professor Kerst invented the betatron—which made Hansen's scheme seem impractical—not until somebody could invent a source of microwave power which would be much higher than available to Hansen in 1935 and 1936. The second reason was that just about the same time two brothers arrived at Stanford, the Varian brothers. They had a fantastic idea: They wanted, first of all, to try to prevent bombing attacks of the United States by the

German Air Force; and they wanted to invent a way of making it possible to land airplanes safely despite bad weather. These plans were born in the mind of Sigurd Varian, a Pan-American pilot flying to South America where he was often in trouble—as Senator Bennett was recently. These difficulties made him realize that something had to be done about these very urgent problems.

The two brothers decided to abandon their good jobs in industry—Pan American in one case, and an industrial concern in the East in the other—and settle down in their native town on the coast of California and proceeded to work on these difficult problems.

Russell Varian, being a physicist, knew what kind of problem he was working on. He knew that in order to penetrate space in darkness and in bad weather, he would have to "invent" radio waves which could be focused in space like light is focused by searchlights. He knew he was after microwaves.

Varian brothers spent approximately a year working on these problems, but they just could not get started. They decided then that the difficulty with their ideas was that they were working by themselves, in a vacuum, and that they should go to Stanford where they might be aided by stimulative discussion with other scientists, where they would have facilities, and a library to refer to.

They came to Stanford and were welcomed by Professor Hansen and others of Stanford University, and there began a period of fantastic productivity. Russell Varian began to invent various kinds of devices that could produce microwaves. He invented about 20 devices which could possibly work, but each one of them Professor Hansen took apart as being useless. Finally there arrived an idea which Professor Hansen could not find fault with, and Sigurd Varian put it into practical form. Within a month's time the device, the klystron, became practical. The first sketch of the klystron was published in 1948 and became a "blueprint" useful for radar devices throughout the free world.

I need to digress further to say that in late 1940 the Stanford group was invited to come to Sperry Gyroscope Co.

Representative PRICE. How long have you been connected with this project?

Dr. GINZTON. Since 1939.

Representative PRICE. You played a small part in this yourself?

Dr. GINZTON. A small part.

Representative PRICE. That is not the way we understand it.

Dr. GINZTON. The Stanford group was asked to come to Sperry Gyroscope Co. to help establish that company's electronic and microwave activities. We stayed there during the war.

In 1945, Professor Hansen returned to Stanford and resumed work on his linear accelerator ideas, the ideas he had formerly established in 1935, but with the major difference—during the war the magnetron became available—a very powerful source of radio waves which made possible for Hansen to demonstrate the value of his early concepts. He built, very soon after he returned to Stanford, a machine which we now call the Mark I, which provided, in the course of time, 6 million volts.

In 1946, a number of us also returned to Stanford from Sperry and began to work on other ideas which, in some ways, were unrelated. We were very much aware of the fact that Professor Hansen's dreams of building perhaps, a billion-volt accelerator could not possibly be achieved even with the world famous magnetrons. Something more powerful was needed.

A number of us were also aware of the fact that new kinds of radar transmitters were essential. Because of these two needs, and also because of the pure intrinsic interest in demonstrating something that had never been done before, a number of us embarked on the idea of developing the world's most powerful radio tube—which we decided to build in the form of a klystron.

We built the first multi-megawatt klystron in 1949, and it soon become the heart of further developments of Professor Hansen and his associates.

Representative PRICE. What part did this play in the radar?

Dr. GINZTON. If I may, I would like to show you this klystron tube. (See fig. 16 in Ginzton's prepared statement, p. 160.) This is a tube which was designed by us in 1948–49. It was first demonstrated in practical form in 1949, and became the heart of microwave linear electron accelerators at Stanford and elsewhere. This tube became the "father" of a family of klystrons; bigger and smaller; bigger in average power; smaller in peak power; shorter and longer wave lengths. It is used in the American defense system in the DEW line, and in other important systems which I would rather not mention.

Representative PRICE. Is it essential in radar?

Dr. GINZTON. Not in all forms of radar; but there are many forms of radar which could not be built without a klystron. I would like to mention, in passing, that a number of klystrons which are patterned after this one were, in fact, developed in our laboratories and later on transferred to the industry for production. Industrial ingenuity has now resulted in many similar klystrons.

Representative PRICE. What is the cost of such an instrument?

Dr. GINZTON. It depends on the quantity that is produced. We at Stanford make these tubes for $3,000 to $6,000 depending on how many we make at a time. The production costs of tubes of this sort are perhaps about $4,000, a number typical for large quantities.

Representative PRICE. Are they all the same size?

Dr. GINZTON. They come in various sizes. For shorter wavelengths they come smaller; for longer wavelengths, they come much, much larger. The DEW line is equipped with tubes which are approximately this size.

Senator BENNETT. That is the modern adaptation of the original Varian invention?

Dr. GINZTON. Yes, sir. This is a klystron. In fact, it is no different from the klystron that Varian invented in 1937, and built in 1938. It is different only in the fact that it delivers about a million times as much power as was developed by the early Varian klystrons.

This klystron today is the world's most powerful radio tube—at any wavelength.

As a result of the availability of this particular tube, it was possible for us at Stanford to embark upon the development of linear electron accelerators with an entirely new perspective. A tube of this

sort would make it possible, with a linear accelerator 10 feet in length, to develop millions of volts of energy.

I will come back to this point later. I am now trying to give you a historical background of how we came to be interested in this field. I will come back to the use of this tube later.

As a result of the accelerator activity, there developed a series of machines. The most important one was the so-called Mark III accelerator, which you have heard about before and to which I will refer again. That activity, however, was not the only one. We built approximately 10 linear electron accelerators, which I have listed in my statement—and you see that our interests have been diverse. We have built linear accelerators, in a number of cases, for the purpose of research in nuclear physics. In other cases, for the purpose of carrying out cancer treatment with X-rays or even directly with electrons. A number of these machines are in operation in various parts of the United States, as well as in other parts of the world.

Representative PRICE. As a matter of curiosity, what is the size of your Mark III which you show in figure 9 (p. 129) of your statement?

Dr. GINZTON. The Mark III accelerator, sir, is 220 feet in length, powered by 22 klystrons. Not all the klystrons are always connected, but that gives you the idea. That provides, at the present time, 730 Mev. That machine is now expanded to 300 feet in length. It will be powered by 30 klystrons, and will develop something over 1 billion volts.

If I may, I would like to digress again and tell you something about the principle of operation of how a linear accelerator works. You may have greater confidence in our proposal if you have an insight into the operation of this device—which is not really very complicated.

The simplest possible linear electron accelerator is a device which you can find in any home radio set or in dental or medical X-ray equipment. Referring to figure 3 (p. 111), is what we call in electronics a diode. It consists of a vacuum container—which I have not shown—a thing called the cathode, and a plate called the anode. If the filament heater heats the cathode, the electrons are forced to evaporate from the surface, and become available in front of the cathode. If we connect, by means of wires, a battery as shown, then the electrons find themselves facing the positive plate and are attracted to it, that is are accelerated in that direction. If the battery happens to be a 6-volt one, then the electrons will acquire upon arrival at the anode a certain velocity; we can then describe this "machine" as a 6-volt linear electron accelerator, or for brevity's sake, 6 ev. accelerator. In the case of high-energy accelerators, we add M or B to stand for million or billion volts.

This machine could be made a 12-volt accelerator by putting another 6-volt battery in series with the first one. The difficulty with this approach is that, first of all, every time you want to double the voltage, every time you want to add 6 volts, you have to pay for another battery, and this is very expensive. There are other practical reasons why this idea is not a good one, but the cost is one of the most important ones.

This demonstrates, in the simplest form, the linear accelerator. The fact that it is impractical for high energy machines makes it necessary for us to seek other solutions. I shall try to show you how a real linear accelerator works. Referring to figure 4, page 113, this is a device called the boy accelerator. Suppose we imagine that a seagoing wave approaches the beach, like this. Suppose we imagine that we have a boy who has a surfboard, and that he places the surfboard on a forward part of the wave, in such a way that the boy is looking downhill; this then will cause his board to slide down the wave. If the boy adjusts his position on the wave in such a way that his forward motion happens to equal the forward velocity of the wave, then he will not, in fact, be sliding down and will be captured by the wave and be accelerated toward the shore. If the wave speeds up—as it gets into shallow water—so will the boy speed up, if only he is clever enough to remain on the proper part of this wave. This process of acceleration we call a linear boy acceleration, and is closely analogous to the kind of device we are trying to propose for our electron machine.

What we are after is this. We are trying to accelerate the particle—the boy—to very great velocity, without having to have immense waves. So we have an alternative before us. As in the case of a battery, we can get very large acceleration by using very large accelerating potentials, or as in the case of a boy, we can exploit the wave.

Let us imagine that we have a pipe—a copper pipe—perhaps 4 inches in diameter, into which we feed power from a very powerful radio transmitter, as indicated in figure 6 (p. 116). As you know, no doubt, there are regions in the wave which are positive and others which are negative. Suppose we then imagine that an electron is located just behind the positive wave crest. This wave crest will attract the electrons just like in a battery, and cause them to move forward with the waves. So the picture consists of a wave and the electron speeding up together, just like the boy does on the surfboard.

If I may use another crude analogy: think of a boy riding a donkey, holding a carrot in front of the donkey's nose by means of a stick. The donkey looks at the carrot and runs after it, but the carrot is always ahead of the donkey.

The velocity which the electrons acquire have to do with two different things: One, with the power of the radio waves; second, the length of the accelerated waveguide. You all know one cannot propagate radio waves indefinitely, and the pipes which we visualize—for practical reasons—turn out to be about 10 feet.

Also, there is obviously a limit as to how much radio frequency power one can generate. These klystrons, which generate up to 30 megawatts of power, produce about as much power as we can generate conveniently. For example, an energy of about 45 million volts can be generated, if one uses a pipe 10 feet long, and a power of 24 megawatts from the highest klystron we can make.

But as you know, our interest in high energy physics extends beyond 45 million volts. Therefore, this machine in its present form would not be of practical interest. But we consider this machine to be a "building block." If this machine, 10 feet long, provides 45 million volts, there is no reason why we should not take these electrons

at 45 million volts, inject them into another machine, and add another 45 million volts energy; and thus the process can be continued, using this concept of a building block indefinitely—around the world, if you care to. The only problem would be money.

The real pipe appears like this in figure 7 (p. 119); I will show you a model in a few moments. I show this because I want to indicate that the pipes are not just uniform round pipes. Uniform pipes will not work, because the velocity of the waves through these pipes is not correct. The boy on the wave has to adjust his position on the wave such that he is always in the proper position, going neither too fast nor too slow.

Representative PRICE. You said the only problem is money. I was thinking some place you would have to make a turn or it would not be linear.

Dr. GINZTON. I will come back to this, sir, if I may. There is an answer to that.

The important thing here in our accelerator is to be sure that we can duplicate the behavior of a boy accelerator. Since electrons are not animate, and cannot adjust themselves to the wave, we have to think the whole process through, from the beginning to the end. We have to adjust the velocity of the waves so that, as electrons speed up, the wave speeds up in proportion. This we do by adjusting the specific dimensions of our pipes which are made to look something like this [indicating], and by carefully adjusting of the dimensions, inch after inch, we can get the waves to stay in step with the electrons.

This, gentlemen, is a photograph of our Mark III accelerator which was referred to a number of times today (fig. 9, p. 129). It is a machine which is 220 feet long. It is powered by 22 klystrons of the kind which we build at Stanford. Electrons are injected at one end of this pipe and progress through it for a distance of 220 feet, at the end of which they escape from this machine and become useful for research purposes.

As you can see, there is not very much to this machine. There is the pipe, there are the klystrons; there are also various kinds of other components needed to either cool the pipe or to provide electrical power to the klystrons. But the principal basic components are just the pipe itself and the klystron.

The Mark III machine which I have just shown is the cornerstone of our proposal, gentlemen. In the first place, it is an example of this "building block" principle, in which the basic design is repeated over and over and over again.

The history of the machine that you have seen I might run over just briefly.

It was proposed in 1948. The actual construction was begun in 1949 under ONR auspices. The high-power klystron was developed at that time and demonstrated as a successful product in 1949. The machine was completely completed in 1952. Partial research was begun in 1951, and the machine has been in use ever since.

In 1951 the energy was about 160 Mev. making it possible for Professor Hofstadter to begin his brilliant research on the size of the nucleus. The current energy of Mark III machine is 730 Mev., and is being expanded to 1 billion volts.

I should like to mention specifically another machine—one which is much like the Mark III, but much shorter; it is the Mark IV, which was begun in 1954 and completed in 1955. Mark IV was built for two specific purposes. One was to provide us with a background of information for machine improvements—which might be useful in any future multi-Bev. machine that was clearly foreseen. This machine is 20 feet long, powered by two klystrons. It is a simple machine to operate. It is not very expensive. The results from this made it possible to improve many of the components which are needed for any big machine, and in fact made it possible for us to improve the reliability of the present Mark III machine.

The Mark IV accelerator is the test vehicle for new ideas and concepts. It is the Mark IV which developed the specific information which is needed for design of the proposed 2-mile machine.

I would now like to begin to talk about the present proposal gentlemen.

The present proposal, in our minds, dates back to 1952. We finished the Mark III machine at that time. It was perfectly obvious to us that there was no reason why a bigger machine should not be practical. We began discussion among ourselves for that purpose. We were able to obtain a grant from AEC to build the Mark IV accelerator and to finance some other research work of that kind.

In 1954 we were able to write the first report which stated clearly—to us and to others—that the machine for 50 Bev. energy would be practical. There would be no technical reason why it would not work.

So our proposal developed over a period of time, first of all on the basis of feasibility studies, then on the basis of component improvement. We then developed the cost estimates. In the way you have heard described before, we developed a proposal which was submitted to the Government in April of 1957, which is being discussed today. I would just like to very briefly run over the main elements of this proposal.

The machine we are proposing is listed in the first column, table I (p. 131). It is a machine to be 10,000 feet in length. It is to be powered by 240 klystrons, each delivering approximately 6 megawatts of power at the very minimum, but capable of 24 megawatts. The machine, if operated with klystrons with maximum possible power, could deliver 22.5 Bev. We think that the klystrons that we can build today can operate very conservatively and effectively at 6 megawatts. So the actual energy which we are recommending today is 10 Bev. and not 225 Bev., which this machine could reach, if pressed.

The pulse rate is 360 pulses per second, a number which is probably of no direct interest to you. What is important is that this machine will deliver, in the form of an accelerated beam, approximately 0.6 of a megawatt in electrical power. This is a fantastic amount of beam power.

In the second column of table I we list the characteristics of this machine if it were extended to full energy by increasing the power capability by furnishing 960 klystrons—at which point the power in the beam would be 2.4 megawatts at an energy of 45 Bev. This is an extremely large amount of power in the electron beam.

The next chart demonstrates to you, I hope, how it will be possible for us to increase the energy capability of this machine from the 10 to 15 Bev. range to the final 45 Bev. What this shows is that pipe, 10,000-foot pipe, is fed with radio-frequency power every 10 feet. Power from a klystron is split four ways and taken to join feed points spaced 10 feet apart. When it is necessary or desirable to increase the energy of this machine, all one needs to do is to buy more klystrons and to plug them in, as shown in the lower part of figure 14 (p. 150). Nothing further needs to be done except to procure more radio-frequency sources.

This expansibility we regard to be a very important part of this proposal. The fact that (if and when a higher energy machine is needed) it will not be necessary to plan again 10 years ahead and to ask again for a very large sum of money is a most important feature of this proposal. For a very nominal investment compared to the original one, it will be possible to extend this machine to 45 or more Bev.

Just one more point, in passing, that I should like to make. You might ask: How is it possible to get particles through a pipe which is only actually three-quarters of an inch in diameter for a distance of 10,000 feet? If you try to imagine getting any kind of particle from any kind of gun to hit a spot three-quarters of an inch in diameter 2 miles away, it would obviously be extremely difficult, if not impossible. The difficulty, however, is not real because of a very interesting characteristic of relativistic electrons. We have been talking about these accelerators as if they are "accelerators." In fact, what happens is that the velocity of the electrons reaches practically the velocity of light within a distance of about 1 foot, and after that only the mass of these electrons increases. In this particular machine the 10,000 feet of pipe does not seem like 10,000 feet to the electrons because of the theory of relativity. To the electrons, moving at the velocity of light, the whole pipe appears foreshortened, so that a mile of the machine becomes about a foot.

Mr. Chairman, this is a section of the linear accelerator that we propose to build and I would like to have you look at it, if you will (sample shown 8 inches long, not unlike the illustration shown in fig. 13 (p. 149) in cross section).

The basic elements of our proposal, gentlemen, are two specific things: First, the klystron, which is essential to generate the radio frequency power; the second is the accelerator "waveguide." I did not talk much about the waveguide, simply because it is too difficult to discuss it in detail. However, one of the most important things about it is the precision with which this pipe must be made. Even though the machine is 10,000 feet in length, all dimensions inside the pipe have to be held to approximately one-tenth of a thousandth of an inch. This is fantastic tolerance.

Representative PRICE. Doctor, are the components you have developed for the Mark III and Mark IV substantially the same as those you will use in your proposal?

Dr. GINZTON. Yes.

With the aid of the AEC grants in the last few years, many improvements have been made which make them cheaper and more reliable. This development effort is not yet finished.

I would like to indicate one specific proposal which is now being tested. This has to do with the method of fabrication of linear electron accelerator, a very important step in our process. What I am about to describe is the process which we are trying to use to fabricate the waveguide section that you have in your hand, with the precision of a tenth of a thousandth of an inch. The way this is done is, first, to fabricate a series of copper disks—which are obviously very simple—and aluminum spacings. Then what we do is stack up the aluminum pieces on top of copper pieces until we have a structure as long as one wishes, such as 10 feet. This is then held together by a bolt. The whole structure is plated with copper until the coating becomes about three-eighths inch. Then we take out the bolt and etch the aluminum. We then have left this structure here—that is the end of the process.

This process was invented at Stanford University and tested with the aid of AEC and other grants. It represents the kind of development activity which we feel is very important to completely test to insure that the 2-mile machine is made as economically as is feasible.

I mentioned the klystron and the accelerator waveguide simply because they represent the most important elements of our proposal and represent examples of the kind of things we shall have to develop further in our program.

Since the next chart (fig. 12, p. 143) shows what you have seen before, I will just mention it very briefly. It lists all of the accelerators above 10 Bev. in the United States or anywhere else in the world. As you can see, above 10 Bev. there are four proton accelerators which are being proposed, and none except ours for the electrons. Ours is the only electron machine in the world that is being proposed for 10 Bev. or above.

This machine is also unique because of the power. The sixth column lists the average beam power to be furnished by the various machines. In the case of the four proton machines, the beam power is about 50 watts or thereabouts, roughly the power consumed by an ordinary light bulb. We propose to build a machine which will generate about a million watts. This is the important characteristic of this machine that was referred to by Dr. Williams and Dr. Haworth in their earlier testimony.

Figure 2 shows the various cost estimates presented to you as given in the data sheets. This information was derived from an original Stanford proposal, modified in the Brobeck report, and finalized in the AEC review. You have seen this information before in another form.

The first column is the $105 million budget estimate: $8 million is for engineering and design of the machine after development activities have been completed; $41 million represents the cost of the tunnels, buildings, and so forth. The accelerator pipe itself, and things that relate to it, represents $24 million. Various kinds of equipment needed in the project is $10 million; other costs are self-explanatory.

Mr. RAMEY. Are the tubes included in your accelerator cost?

Dr. GINZTON. This item of $24 million?

Mr. RAMEY. Yes.

Dr. GINZTON. Yes, sir.

The second and third columns show the breakdown by years, and I don't think I need to explain them.

Construction request for the first year is $3.7 million; the construction request for future years is vastly different, depending on the nature of the activity, being the largest in the middle of the period.

Representative PRICE. Why do you estimate that the operation requirement will drop between fiscal year 1963 and 1964?

Dr. GINZTON. These are procurements of various major items. This is not operational. This is construction which has to do with obligation for tunnels, for example.

Mr. RAMEY. You will be incurring operating costs during that period along with your construction at some stage?

Dr. GINZTON. In the fourth or fifth year of the program some research cost will have to be incurred.

Mr. RAMEY. While you are building up staff?

Mr. GINZTON. Yes.

Mr. RAMEY. When you are building up staff at present will it all be charged to your construction program?

Dr. GINZTON. No; the costs portrayed by these charts and budgeted at $105 million are construction costs only. It is perfectly true that as construction activities drop off some of the same individuals will become useful for research. But requests for financing that kind of operation will have to be made later in the fourth or fifth year. We visualize that by the time the machine is completed and by the time the seventh year begins, the machine will not only be built, but a staff of people will be available to employ the machine usefully. That group cannot be created by magic. It will have to be created in 4 or 5 years, with the hope that many of the people will come from the construction crews, except for the scientists.

Representative PRICE. Does this mean that $105 million will be spent up through the fiscal year 1965?

Dr. GINZTON. I cannot keep track of your fiscal years.

Representative PRICE. It is the last fiscal year you mention on your chart. It is $12 million for fiscal year 1965.

Dr. GINZTON. The answer, I think, is "Yes."

Representative PRICE. Mr. Floberg, what about the Commission requesting a supplemental appropriation for fiscal 1960 for this project?

Mr. FLOBERG. It is the figure that is at the bottom of the obligation column there, which I believe is $3.7 million.

Representative PRICE. What year is that?

Mr. FLOBERG. That is 1960.

Representative PRICE. Is that the amount you are going to ask for?

Mr. FLOBERG. Yes.

Representative PRICE. That question will be asked of us, Why do we authorize the full amount of $105 million when we intend to request only $3.7 million in appropriations?

Mr. FLOBERG. I tried to answer that question this morning, Mr. Price, in the course of our discussion.

Representative PRICE. You were not speaking in terms of the great difference of what you are actually going to have in money and what you are authorized.

Mr. FLOBERG. It is perfectly true it will take 6 years to develop this machine as a living being. It won't take that long to develop it as a project for construction. The answer I gave to your question this morning was intended to answer this last point you raised.

Representative PRICE. The point is that you are going to start some actual construction in fiscal 1960.

Mr. FLOBERG. Yes, sir.

Dr. GINZTON. Perhaps some of these questions can be made more clear by looking at figure 17 which shows the scheduling of various kinds of activities with time. Point marked "zero" represents the beginning of authorization, whenever this occurs This is the first, second, third year, and on up to the 6 years. The first column lists the various activities which have to do with construction of this whole project. The blue color is used for design of various kinds of things, for example, the general shops. The red is used to describe the construction activities, and yellow, the tests. As you can perhaps appreciate, this project is extremely complex in nature. There are many, many components involved. We need to make a broad attack on the problem from various points—klystron development, power development, accelerators, buildings, shops, research equipment, magnets, everything else. There are dozens and dozens of things that need to be started. This chart shows, for example, that it will take us 6 months, we think, to take this klystron which is before you—which was designed in 1949 and is still in use today—and to develop it into the kind of model that will be economical to produce when made in quantities of several hundreds. It needs to be completely redesigned mechanically, because there are problems which pertain to economy and reliability. So we propose to spend 6 months on this. But within 6 months, we think, this process will be over, and we need to make samples which need to be tested in preparation for manufacture.

The chart contains many items which obviously you cannot think about in detail now. It does show you, I hope, that it is a very complex project, with many things keying in together. It is virtually impossible for us to segregate one specific thing and say we will work on its design. It makes no sense, because so many things have to be started together, if the project is to be completed in 6 years.

Representative PRICE. The appropriation of $3.7 million is that based on the maximum effort you can make on this project in the next fiscal year?

Dr. GINZTON. Yes, sir. This is to be supplemented by an additional amount of $1.8 million requested for so-called research and development activities, which do not appear as a part of the $105 million.

Representative PRICE. There is nothing else you can do in the next fiscal year, even if you had the money, to expedite the date when the project would be completed?

Dr. GINZTON. That is correct.

Representative PRICE. Nothing; no facilities that you could build?

Dr. GINZTON. The facilities we need to build are included in this For example, general laboratories. The staff which we have now is approximately 25 senior people, or 45 altogether. We need to build up this staff to approximately 150 people during the first year. We cannot house these 150 people. We have scheduled things in such a way that at the end of the first year buildings would become available

to house the first group. This is an example. There are many other examples. Klystrons need to have test facilities. These facilities need to be procured. That involves construction money.

Representative PRICE. The $1.8 million is already available?

Dr. WILLIAMS. That $1.8 million is a part of the $18 million of research and development. This was contained in the budget which you authorized and which we already presented to the House Appropriations Committee as a specific part of our operational budget.

Representative Price. If this project is authorized, when will the Commission request appropriation for the $3.7 million?

Dr. WILLIAMS. As soon as it is practical to do so.

Mr. FLOBERG. As soon as we can move on it.

Representative VAN ZANDT. Suppose at this session of Congress we authorize and appropriate, when will this 6-year period begin?

Dr. WILLIAMS. The 6-year period will begin just as soon as we can firm up the arrangements with Stanford and they get at least the intent of contract so that they can get started. We intend to go at this with all the vigor that is possible, provided the authorization is granted and the appropriations are made.

Mr. MCCARTHY. I would like to add to that, if I might, Mr. Chairman, that the $3.7 million for the construction would be sent to the Congress as a supplemental fund request. It is my understanding that the House has now sent through its last appropriation bill, and that all requests for supplementals are now going to the Senate. Our bill, as you know, will probably be reported out of the House this Friday. We would hope, if the committee authorizes this project, to have the supplemental request forwarded to the Senate so it could be included in our regular appropriation bill as it is considered by the Senate probably next week.

Representative VAN ZANDT. Should Congress appropriate the $1.8 million and not the $3.7 million, what effect would it have on the overall program?

Dr. WILLIAMS. What we are asking this committee for is the authorization for the project as a whole at this time.

Dr. GINZTON. If the project is not authorized, I believe it would have very serious impact upon the whole program. I think the whole question before us and before the whole world is whether this country intends to or does not intend to build such an accelerator. If it is partially authorized, there will be an open question before everybody. It means we will not be able to obtain the services of prominent people, who will have serious misgivings about permanent employment. As a result, the project will not be designed with the excellent staff we need. It will take longer to build and will cost more. I think it is much better, from my point of view, to have the project either authorized or not authorized, but not left hanging.

Representative PRICE. That leads me to ask a question. Where are these people coming from?

Dr. GINZTON. We are beating them off, essentially. This is the most fascinating activity of this kind ever proposed. We have applicants from all over over the world, excluding Russia.

Representative BATES. Why do you start building the laboratories early?

Dr. GINZTON. Because we need, for design purposes, a staff of about 150 people altogether, in all categories. We can only house 25 or 30 presently. In the first year we will completely run out of available space for men and equipment. We need facilities very, very badly.

Representative BATES. Is it that aspect of construction work that they will be working on?

Dr. GINZTON. The work progresses in several stages. First of all, there is improvement in components. That is the first category across the whole front. Second, the general design. Instrumentation for the machine, control, reporting of data, all this has to be designed. The construction activities for which construction funds are needed are to provide space for men to work in and test facilities to test components as they are developed.

Representative BATES. This will be at the same site?

Dr. GINZTON. Yes.

Representative BATES. Then you will continue to use the same laboratories later on?

Dr. GINZTON. Yes. Figure 1 (p. 108) shows the aerial view of our site. This is Stanford University here. This is the site which is reserved for the project. This distance is 2 miles, and in this area we propose to develop laboratories which will be first needed for development activities and later on for administration and research activities connected with the beam end of the machine.

Representatives BATES. So the R. & D. work on this whole project will be done at the site?

Dr. GINZTON. That is right.

Representative BATES. That is why I did not understand. I wondered why you wanted it 3 years earlier. It will be the same people who will continue.

Dr. GINZTON. Yes, sir.

Representative BATES. They are of that nature.

Dr. GINZTON. Yes, sir.

Representative VAN ZANDT. Doctor, I notice in your statement you say that this project is the largest single expenditure of funds for a single-purpose research activity. Is that why you used the word "fascinating"?

Dr. GINZTON. Yes. That is not the only reason. I think it is unfortunate that the project costs so much money. Those of us involved in research do not cherish the idea of spending so much money. We would rather do much more interesting things than that. Nonetheless, we accept the challenge of spending so much money because the consequences of this are so important and so fascinating.

Representative VAN ZANDT. In your summary you say that much of the fundamental information about the nuclear world is yet imperfectly understood, making it impossible to establish a specific research program for a multi-Bev. machine far in advance. In other words, are you saying we have not yet scratched the surface in this field?

Dr. GINZTON. We have scratched it. I am afraid there is a lot to scratch yet.

Representative VAN ZANDT. In other words, you are not under the surface yet.

Mr. FLOBERG. I am not sure that the previous question that Mr. Van Zandt asked 3 or 4 minutes ago was properly interpreted, and it may have been misanswered. Did I understand your question to be, Suppose the Congress appropriated the $1.8 million this year, but did not appropriate the $3.7 million?

Representative VAN ZANDT. That is right.

Mr. FLOBERG. The answer to that question is that there would simply be no construction started this year and that much time would be lost. I thought that is what you meant.

Representative VAN ZANDT. In other words, we would lose a year.

Mr. FLOBERG. We would lose whatever the time was.

Mr. RAMEY. You could use your operating money for the so-called title I work.

Mr. FLOBERG. Yes.

Mr. RAMEY. Or even title II work like you are going to do for the superheat reactor.

Mr. FLOBERG. There might be some slack taken from that money, but there would be no buildings or construction or anything of that sort, and there could be no actual construction done from that money.

Representative PRICE. What is the first type of actual construction you intend to do?

Dr. GINZTON. There are two things we intend to build almost immediately. One, are the laboratory buildings, shops on site, which will go eventually into the complete operating plant of this project. This is essential for the project to make any headway. The second thing is that we have components that have to be developed as we have mentioned before. These components need to be tested. We need facilities of various kinds. Space, but also electrical equipment of various kinds to make tests possible. We need to procure that, which involves construction funds as well.

Representative VAN ZANDT. Doctor, is it true that we as a Nation are bypassing many research problems for the purpose of establishing our leadership worldwide in this particular field of high energy physics?

Dr. GINZTON. Mr. Chairman, I might like to ask Dr. Williams to try to answer that question.

Dr. WILLIAMS. As you know from reviewing our budget every year, we do have a broad base program in all energy regions. I personally think the answer to your question is "No." We have a coverage which, although it might be bigger, we feel to be quite adequate, and we are in no sense jumping over regions which we believe, from the best scientific judgment we have available, are lying dormant. This is a growth at the forefront, but not neglecting the broad base.

Representative VAN ZANDT. It is a project which could establish for us world leadership.

Dr. WILLIAMS. There is no question about that. We would be the leaders in this particular area of high energy research.

Representative PRICE. You say this project will establish for us world leadership in the high energy field?

Dr. WILLIAMS. In the high energy electron accelerator field it will establish it.

Representative PRICE. Does that mean you feel we do not have it now?

Dr. WILLIAMS. We are comparable in energy with our electron accelerators to those in France. In the circular machine, the one at Hamburg and one at Harvard are the same. So this is a move out ahead.

Representative PRICE. What you are actually saying is that a lot depends upon the size of the machine you have with regard to the position you have in this field?

Dr. WILLIAMS. That is one way of looking at it, yes. I believe we are justifying this machine on the kind of physics we want to do. We want an energy so we can explore what we see is available for exploration. I don't think we want to belabor the point or I don't want to try to present this to you as a way of beating the world.

Representative PRICE. I am trying to establish the necessity of a machine of this type.

Dr. WILLIAMS. It was described by Dr. Haworth to explore these mysteries that we see clearly before us. That is the basic reason the policy was developed, and we in the Commission support it wholeheartedly.

Mr. FLOBERG. It is not like the horse race in power.

Representative PRICE. It is the intensity and kind of machine.

Dr. WILLIAMS. Yes. These attributes are the ones we want for doing the research we want.

Representative PRICE. It is not a kilowatt race.

Dr. WILLIAMS. No.

Representative VAN ZANDT. Where do you go 6 years from now?

Dr. WILLIAMS. In the electron field we want to look at this particular accelerator and the state of the art, and if the scientific justification exists come back to you gentlemen, more than 6 years from now, because this won't be finished—about 9 years from now—and say physics looks like this. From this modest sum percentagewise, we can look at these new problems.

Representative BATES. And expand this one.

Dr. WILLIAMS. By expanding this one.

Representative PRICE. I think the point I was trying to get is regardless of the great minds we have, and the genius in the theoretical people we have, in order to attain leadership in this field, you cannot just depend on the human being. There are certain machines which are necessary.

Dr. WILLIAMS. There are no tools that come without our building

Representative PRICE. You have to have special tools?

Dr. WILLIAMS. Yes, sir. Without them we are stopped.

Representative PRICE. Doctor, do you want to continue?

Dr. GINZTON. Mr. Chairman, I have only a few more words to say. I would like to leave you with the impression which to me is very important, that this machine is being proposed to you not as a novel kind of machine which needs to be experimented on, but in fact it is an extrapolation of known techniques, and we are absolutely certain that the machine will work.

Secondly, I would like to say that has been said several times today already, that if this machine is built, it will be a national asset, and a unique one in the United States and throughout the world.

Thirdly, the last point, which is important to me personally, is to leave with you the impression that we are ready to begin construction.

We have been waiting for a long time for authorization, and for which we have not been waiting impatiently; we are ready now.

Thank you, sir.

Representative PRICE. Thank you very much, Doctor.

Are there any questions of Dr. Ginzton?

Senator BENNETT. I had the privilege of spending half a day with the Doctor and other members of his staff at Stanford, and I am impressed most of all with what he said at the very end of his statement, namely, that all of the basic research and the basic testing and the basic construction techniques have been worked out, and this is a problem of extrapolating a known success and multiplying its capacity, and that ability to multiply its capacity does not depend on problems yet to be solved. Those problems have basically been solved. The equipment can be improved. Its capacity can be increased. But it is not intended that it will be changed in any substantial concept. I think that gives us a tremendous advantage in starting on this national project.

Dr. GINZTON. Mr. Chairman, if I may add a remark to this, I am very happy to have Senator Bennett make his observation. This is the exact feeling we have. I would just like to say we are very happy to be in the particular situation that we are able to extend our machine energy without having to resort to research or development of new concepts. We would not like to leave the impression, however, that this is not the only approach to experimentation in the future. Other people have other proposals to make which do involve research and development; and we are not saying that ours is better than theirs. We are just stating our position clearly in our case. We can build a machine which we think can be extremely useful by direct extension of known techniques. It is not an argument against anybody else who may wish to develop novel concepts which might be superior to ours.

Representative PRICE. Doctor, you referred all the way through to the national asset. What comment would you make about participation of scientists from other universities and national laboratories? What plans are actually being set up?

Dr. GINZTON. There are two kinds of answers. First of all the operation at Stanford, as well as other places in the United States where these machines are operated, we have foreign visitors. We have exchange visitors all the time. We don't reserve our facilities to just our own staff. At Stanford University, the principal leadership exercised in the physics department in this field is due to two people, Professors Panofsky and Hofstadter. The new machine will provide opportunity for more. Stanford University does not intend to extend its physics department; the bulk of the facilities will be available to qualified scientists regardless of where they come from.

Representative PRICE. For the years that the project has been underway, have you had participation of scientists who are not directly connected with Stanford?

Dr. GINZTON. Yes, sir, we have from many, many places.

Mr. FLOBERG. Mr. Chairman, with regard to the $3.7 million, I would like to call to your attention that only $175,000 of that is engineering and design money that could properly be classified as title 1. If you would like me to submit a breakdown of the $3.7 million at this point in the record, I will do it for you.

Representative PRICE. I am glad to have it.

The information follows:

Engineering and design	$175,000
Improvements to land	435,000
Buildings: Klystron laboratory administration	1,112,000
Utilities	540,000
Klystron test stands	500,000
Equipment	560,000
Contingency	378,000
Total	3,700,000

Representative PRICE. The committee will recess until tomorrow morning at 10 o'clock, and we will meet in the same room. The first witness tomorrow morning will be Mr. William Brobeck, who was originally scheduled as our last witness today. The committee will stand in recess.

(Whereupon at 4:25 p.m., Tuesday, July 14, 1959, a recess was taken until Wednesday, July 15, 1959, at 10 a.m.)

STANFORD LINEAR ELECTRON ACCELERATOR

WEDNESDAY, JULY 15, 1959

CONGRESS OF THE UNITED STATES,
SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT AND
SUBCOMMITTEE ON LEGISLATION,
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D.C.

The subcommittees met at 10 a.m., pursuant to recess, in room P–63, the Capitol, Hon. Melvin Price presiding.

Present: Representatives Price, Durham, Hosmer, and Bates; Senators Hickenlooper and Aiken.

Also present: James T. Ramey, executive director; Edward J. Bauser, technical adviser, and George E. Brown, Jr., professional staff member, Joint Committee on Atomic Energy.

Representative PRICE. The committee will be in order.

This is the second day of public hearings on the proposed 2-mile Stanford linear accelerator. The first witness this morning will be Mr. William Brobeck, of the engineering firm of Brobeck & Associates. However, before Mr. Brobeck starts his testimony, I would like to advise the committee that we have heard from the office of Senator Bible, stating that he has communications suggesting the use of a tunnel near Virginia City, Nev., as a possible site for this accelerator. He states that it is about a 5-hour drive from Stanford, and the length of the tunnel in a straight line is 4 miles. I would suggest that the Commission at least look into the suggestion of Senator Bible's office in this regard.

Mr. FLOBERG. We will check on that, Mr. Price.

(See app. 12, p. 646, for report.)

Representative PRICE. The committee would also like to have further information, possibly to be supplied by Dr. Ginzton, for the record of the hearing, with regard to the geological survey of the proposed site at Stanford. Is Dr. Ginzton here this morning?

Dr. GINZTON. Yes, sir.

Representative PRICE. Would you furnish additional information for us on the geological survey on the Stanford site?

Dr. GINZTON. I shall be glad to do so.

(See p. 576 of app. 6 for information.)

Representative PRICE. Some of the members felt that we did not get sufficient information on that yesterday. (See also app. 13, p. 647.)

Mr. Brobeck, will you come around, please?

Representative HOSMER. Mr. Chairman, while Mr. Brobeck is coming to the stand, will the record be open for statements by other members of the House or Senate to submit to the committee?

Representative PRICE. Yes.

Representative HOSMER. Thank you.

Representative PRICE. Mr. Brobeck, do you have a prepared statement?

STATEMENT OF WILLIAM M. BROBECK, ENGINEERING FIRM OF BROBECK ASSOCIATES

Mr. BROBECK. I have, sir.

Representative PRICE. Before you start, Mr. Brobeck, I would like also, with unanimous consent, that all charts that appeared in connection with yesterday's testimony be included in the record.

Mr. BROBECK. Mr. Chairman, members of the committee, our firm was retained by the Atomic Energy Commission to review the engineering feasibility and estimated cost of the Stanford 2-mile linear accelerator as described in the proposal dated April 1957. (See app. 1, pp. 283 and 427.) The competence of our firm in this field is based on experience in engineering design and construction of accelerators at the Lawrence Radiation Laboratory of the University of California. In the preparation of our report, we retained Kaiser engineers of Oakland, Calif., as consultants on the tunnels, buildings, and utilities.

From an engineering standpoint, the Stanford 2-mile linear accelerator is unusual for an accelerator project in the extent to which the technical knowledge required for its design already exists. The university is now operating a 200-foot linear accelerator which as far as the basic accelerating process is concerned is in almost every respect an exact prototype of the 10,000-foot machine. The increase in length, although by a factor of 50, introduces only minor technical problems. One reason for this is that even in the 200-foot machine the electrons are traveling so close to the velocity of light that their velocity can be considered constant for the remaining 9,800 feet. Another reason is that the elements of the machine behave in a regular linear fashion which permits accurate prediction of their performance. Finally, as the electrons pass through the accelerating tube only once, the problem of resonances, so important in circular accelerators in which the particles pass the same point many times, does not exist. One result of this fact is that the alinement of the machine is not nearly so critical as that of a circular accelerator in the same energy range.

The principal problems that do arise in extending the machine by a factor of 50 lie in two areas: One is that of transmitting signals for control and observation of the performance of the machine over the unusually long distance. Techniques exist for this purpose; the problem consists of selecting those most suitable and verifying them as part of the development program. The other area is that of achieving the desired degree of reliability in a large and complicated single machine. This problem will be somewhat relieved by the fact that it will be possible to operate the machine with many elements out of service through the provision of alternate equipment and of disconnecting devices. It is expected that means will be developed to operate with part of the length of the machine shut down or even to test and adjust part of the length while the beam is being accelerated by the remainder of the machine. This is possible because the electrons can coast through the section that is out of operation and because test voltage pulses can be applied to a section of the machine without

disturbing the pulses of accelerated electrons which are passing through.

The general reliability of the components must of course be high to meet the operating factor expected. The component reliability problem is similar to but not so severe as that of many military electronic systems. A particular item whose reliability can have a great effect on the system as a whole is the klystron tubes used to supply the accelerating voltage. Frequent replacement of these tubes is planned and the resulting costs are estimated based on the performance of the tubes on the 200 foot machine. A major part of the development program will be devoted to determining and improving the life of these tubes under the operating conditions of the big machine. It should, however, be noted that attaining the high reliability desired and expected is not necessary to the success of the machine as a scientific instrument which is unique in its field.

Housing the accelerator in a pair of parallel tunnels provides an excellent solution to the problem of radiation shielding along the length of the machine. It also permits locating the machine close to the university campus where advantage can be taken of existing facilities. Utility connections to the site are straightforward and involve no unusual expense.

From the geology observed by surface indications and test borings in the vicinity, no unusual problems are to be expected in the tunnel construction. Borings at the actual tunnel location had not been made at the time of our report.

Since the preparation of our report, changes have been made in the specifications of the accelerator. These changes have been made for the purpose of placing greater emphasis on higher electron currents at lower energies. At present an average current of 30 microamperes at 10 Bev. initial energy is planned, compared to the 15 microamperes at 15 Bev. initial energy planned at the time of the report. These changes introduce no new problems and are considered to have no influence on the engineering feasibility of the project.

The costs estimated in our report of June 1958 represent our best estimate of the actual costs to be expected under the conditions and specifications existing at that time. The estimates for research and development in our report assume that the machine would be designed substantially as planned and that new development objectives or efforts to achieve performance differing from that specified would be outside the scope of the project. Our estimate for construction and associated research and development for the project as proposed by Stanford was $116 million. The present estimate for construction plus research and development of $123 million reflects the effect of the changes in specifications and requirements since the original proposal. We have not reviewed these later estimates in any detail, but see no reason to disagree with this result.

Representative PRICE. Thank you, Mr. Brobeck. Would you explain the difference in your estimate and that of Stanford, and that of the Commission with regard to the cost of the accelerator?

Mr. BROBECK. I refer you to a table presented by the Atomic Energy Commission yesterday, entitled, "Cost Comparisons Between Stanford, Brobeck, and AEC Estimates." (See p. 40.)

Representative PRICE. Do you agree with the explanation as to the difference of the cost given yesterday?

Mr. BROBECK. Yes, I do.

Representative PRICE. Do you have any comment to make or are there any other reasons for the differences in the estimates?

Mr. BROBECK. I could go into that in more detail, but I generally agree with their estimates.

Representative PRICE. Was there any other substantial reason for the difference in estimates?

Mr. BROBECK. No.

Representative PRICE. Except for the technical differences that were explained yesterday?

Mr. BROBECK. I might remark that the research and development item has been increased since our study by about $4 million. This is a matter which Stanford has decided that further research and development is desirable.

Representative PRICE. What are the principal differences between your cost estimates and the AEC estimates? That is not entirely research and development.

Mr. BROBECK. No. In this table that I referred to, comparing our estimate with the AEC estimate, the total of the AEC estimate is $123 million, including research and development, compared to $116 million for ours, or an increase of $7 million. Of that increase, $8 million—the increase in item A, engineering design and inspection—is partly research and development, and partly undoubtedly items in project management which we did not include in our report.

The construction costs under item C are increased by $1 million. This is a very small percentage. It is a combination of the effects of increasing the power capacity and decreasing the number of klystrons. These effects to a large extent counter each other. The escalation, item D, has been decreased by $4 million. This is a matter of primarily judgment and expectation of future price changes.

Contingency has been increased by $2 million. This is another item that is a matter of judgment. This makes a total increase of $7 million.

Representative PRICE. You stated your view that you did not have core drilling on the tunnel. How far off would you be in your cost estimates without this information?

Mr. BROBECK. I am not an expert on these matters myself. However the contingency estimated by Kaiser engineers was intended to cover the expectation of what there might be of additional cost. I might note that these core drillings are either in progress or about to start and the exact location of the tunnel would be determined by the results of these drillings.

Representative PRICE. Are there any questions of Mr. Brobeck?

Representative HOSMER. You are familiar with the site visually, are you not?

Mr. BROBECK. Yes.

Representative HOSMER. It is not located in an area where there is no water or underground decomposition?

Mr. BROBECK. No evidence of those difficulties.

Representative HOSMER. Speaking of the klystron tubes, you remarked that there would be a frequent replacement of tubes. Do you know what the life of those tubes is at the present time?

Mr. BROBECK. At the present time the life of the tubes in use on the machine is 1,000 hours. The life estimated in our estimate was 2,000 hours. This was the expectation of the improvement due to the research and development effort.

Representative HOSMER. That is not exactly frequent replacement even under hard operating conditions.

Mr. BROBECK. It depends on what you mean by frequent. It amounts to quite a few tubes a week.

Representative HOSMER. Because of the larger number of tubes.

Mr. BROBECK. Yes.

Representative HOSMER. You also noted that a considerable amount of component reliability is not required in this device. What did you mean by that?

Mr. BROBECK. I was referring to the fact that even if the reliability were low, the machine will produce an output when it does work that is not available otherwise.

Representative HOSMER. The parts and pieces of the machine are not so interconnected with each other that a failure of one of them causes the failure of the other?

Mr. BROBECK. They are to some extent. The parts that fail to operate can often be disconnected from the rest of the machine.

Representative HOSMER. Take, for instance, on the klystrons, what is the situation there?

Mr. BROBECK. The klystron tubes can be removed one by one.

Representative HOSMER. If you had one out, your electron coasts past and is picked up by the next tube?

Mr. BROBECK. The machine will run with a number of klystrons out of service.

Representative HOSMER. That is all.

Representative DURHAM. Mr. Brobeck, are you an engineer?

Mr. BROBECK. I am.

Representative DURHAM. I did not see your background here. Where did you graduate from engineering school?

Mr. BROBECK. I graduated from Stanford University.

Representative DURHAM. Can you tell me what we are going to get out of this 10 Bev. over and above a 6 bevatron machine?

Mr. BROBECK. That is the question for the physicists.

Representative DURHAM. That is the reason I asked you your background.

Mr. BROBECK. I can tell you my idea of it, but I think you would do better if you asked the physicists.

Representative DURHAM. I don't think I have any further questions. I think it is an important matter what we are going to get out of this that we can't get out of 6 billion. We are now up to $123 million. Will this thing go up any higher in cost? Is there going to be another estimated cost of several million dollars before we get this thing authorized and in being?

Mr. BROBECK. I don't think there will be any further increase.

Representative DURHAM. Would this be a firm contract?

Mr. BROBECK. I could not speak for the arrangements to be made as far as construction is concerned.

Representative DURHAM. You have an engineering firm. Would you take a firm contract on it as it stands today?

Mr. BROBECK. We would take a contract for the engineering, but not for the construction.

Representative DURHAM. Not for the construction?

Mr. BROBECK. No, sir.

Representative DURHAM. You would take only a firm contract on the engineering part of it?

Mr. BROBECK. That is right.

Representative DURHAM. We have had some experience prior to this on one that has been upped and upped and upped. In your opinion today, can a firm contract be given?

Mr. BROBECK. For the construction of this machine after the detailed engineering?

Representative DURHAM. A competitive firm contract without having to come back to Congress for another $10 or $15 million.

Mr. BROBECK. I think a series of firm contracts could be placed. I don't think any one contractor is in a position to quote on the entire machine.

Representative DURHAM. Of course there would be a series because one would not do the whole job.

Mr. BROBECK. I believe such firm contracts could be placed for the machine.

Representative DURHAM. You have had enough experience in building machines to say that?

Mr. BROBECK. Yes.

Representative DURHAM. I recall the first one because I went out there to see it when Dr. Lawrence was building it. It was not this type.

Mr. BROBECK. As I mentioned, there is an unusual amount of technical background for this machine compared to most of the accelerators.

Representative DURHAM. That is all, Mr. Chairman.

Representative PRICE. You worked on the construction of the bevatron at Berkeley?

Mr. BROBECK. Yes, and several of the other accelerators, also.

Representative PRICE. Mr. Brobeck, would you explain the great difference in the item No. 2 under C in the building, or the $4 million difference there on what is more or less conventional construction? Would you explain your lower figure of $6,534,000 as against the Commission estimate of $10.5 million?

Mr. BROBECK. Our figure was based on very low cost construction buildings which were planned by the university.

Representative PRICE. The same buildings but a little difference in construction?

Mr. BROBECK. Not entirely. I understand that additional buildings have been added. However, I have no details on this. Dr. Ginzton's summary mentions additional buildings which have been added.

Representative PRICE. We will check further into that. Is your estimate of $115,996,000 based on the total at the time that calls for 480 tubes for the accelerator?

Mr. BROBECK. That is right.

Representative PRICE. How would the reduction to 240 tubes change your estimate?

Mr. BROBECK. It would reduce it, of course. I don't have the exact amount in mind at the moment.

Representing PRICE. Could you supply a little additional evidence to the committee on what the estimate might be with the reduced number of tubes? (See app. 7, p. 634, for estimate of cost reduction.)

Mr. BROBECK. Yes, I could. However, I want to mention that there are other changes which increase the cost. I am not sure which items they appeared in. That is the increased power capacity at high energy.

Representative PRICE. What is the date that your estimate was submitted?

Mr. BROBECK. June 1958.

Representative PRICE. You did not take into consideration the reduction from 480 tubes to 240 tubes?

Mr. BROBECK. No, we did not. That was not part of the proposal at that time.

Representative PRICE. How long was your company engaged in the study?

Mr. BROBECK. About 6 weeks.

Representative PRICE. Have you gone into the operating costs and made any analysis of the operating costs?

Mr. BROBECK. Yes, we did.

Representative PRICE. What was your estimate on the operating costs on an annual basis?

Mr. BROBECK. Our estimate was about $16 million.

Representative PRICE. Fifteen or sixteen?

Mr. BROBECK. $16 million. It was $16,756,000, of which $3,725,000 was anticipated capital expenditures during the operating period. That is an average expenditure per year. That leaves approximately $13 million for noncapital expenditures. (See app. 1, p. 430, for operating cost estimates.)

Representative PRICE. What about the cost of power?

Mr. BROBECK. That is estimated also.

Representative PRICE. Did you make an estimate of it?

Mr. BROBECK. Yes, we did.

Representative PRICE. Will you give that to the committee?

Mr. BROBECK. Yes, I will. (See app. 7, p. 635, for power cost estimates.)

Representative PRICE. Do you have it in mind?

Mr. BROBECK. Yes. It is available in our report. Would you like me to try to find it now?

Representative PRICE. If you could give it now, I would like to have it in open session, because the point came up yesterday. The $16 million figure I assume involves the cost of the complete operation, is that right, Mr. Brobeck?

Mr. BROBECK. Yes. There are two power items in our estimate. One is $1½ million, and the other is $210,000. That makes a total of $1.7 million.

Representative PRICE. $1.7 million per year for the power costs?

Mr. BROBECK. Yes.

Representative PRICE. Are there any further questions?

Representative DURHAM. If he has a complete breakdown on the itemized costs, Mr. Chairman, I think it would be well to put it in

the record. (Refer to app. 1, p. 513, for cost estimates originally prepared by Brobeck Associates.)

Representative PRICE. You are going to furnish detailed information. I might say Dr. Ginzton furnished detailed information yesterday, is that true, Dr. Ginzton? You have quite a bit of information in your statement yesterday as to the cost of operation and construction?

Dr. GINZTON. Yes, sir.

Representative PRICE. Do you notice any discrepancy in the figures that have been mentioned here this morning that you would like to comment on?

Dr. GINZTON. There are no discrepancies, sir. Everything is a matter of interpretation, and listing different kinds of costs in different categories. As far as we know there is no discrepancy in the actual detailed numbers or in the ultimate conclusion.

Representative PRICE. Thank you very much, Mr. Brobeck.

The next witness will be Dr. Henry DeWolf Smyth, now connected with Princeton University, but very well known to the committee over the years. He was one of the AEC Commissioners and the author of the famous Smyth report, one of the first documents ever printed on atomic energy.

STATEMENT OF DR. HENRY DeWOLF SMYTH, CHAIRMAN, UNIVERSITY RESEARCH BOARD, PROFESSOR OF PHYSICS, PRINCETON UNIVERSITY

Dr. SMYTH. Mr. Price, thank you for your remarks. I think I am here as an unprejudiced witness in the sense that I don't know very much about accelerators, and high energy physics, and I have no connection with Stanford.

My name is Henry DeWolf Smyth. I am chairman of the university research board and professor of physics at Princeton University. I do not pretend to be an expert on accelerators or high energy physics, but I have had nearly 40 years' experience with research in physics and with the men who carry it out. I understand that the committee would welcome some general background which may be of assistance in evaluating this remarkable proposal which is before you.

The data of science come from observation and experiment. We observe phenomena as they occur around us naturally, or we observe the results of changing the natural environment by experiment. Our tools of observation are ultimately our five senses but we have found ways of extending the power of these senses, particularly the sense of sight. When we look at something three factors are involved: the object itself, the light that illuminates it, and the eye which detects the light reflected or scattered from the object. Often we can extend our knowledge by changing the environment of the object we are studying, by changing the light or by supplementing the eye.

Historically, great advances were first made by supplementing the eye with lenses, that is, with microscopes and telescopes, later by using photography instead of direct visual observation. Even more striking was the substitution of X-rays for natural light. This discovery,

as you all know, revealed whole worlds which had never been seen before. A similar extension of our sense of sight is the use of radar.

Both X-rays and radar beams differ from visible light only in wave length. A stranger, but extraordinarily useful, substitute for a beam of light is a beam of high speed particles. It was by studying the scattering or reflection of the high speed particles naturally emitted by radium that Rutherford first established the existence of the heavy tiny core at the center of atoms that we now call the atomic nucleus. Since that time the scattering of beams of natural or artificial particles has continued to furnish important information about nuclear forces and nuclear structure. Speaking crudely, the degrees to which such particles approach the center of atmoic nuclei increases as their energy increases. Therefore the accelerator in the proposal before you might be described as a searchlight beam to illuminate the dark recesses of nuclei to a degree never before achieved.

As you all know, X-rays not only illuminate, they can cause burns. In general, the beam of radiation or particles used to study a structure may alter it. In medical terms there are side effects. A study of such side effects may be as important, or more so, than the direct study of the scattering or reflection of the beam itself. These side effects also depend on the energy of the particles or radiation in the beam.

One of the most important side effects to be studied with this accelerator is the production of new paritcles, subnuclear particles of which so many varieties have been discovered since the war. The laws which govern the formation and disintegration of these particles remain largely unknown.

Most of what I have said has to do with the general value of machines which give a beam of high energy particles. The experts who testified yesterday and who will follow me this morning are in a much better position than I to explain the advantages of this machine in particular and go into details about the kind of results that may be expected. I can summarize my more general views by saying that undoubtedly results of great scientific value will be obtained from this proposed accelerator, results which could not be obtained with other less powerful machines now built or building. Probably some of these results will ultimately have practical value but his cannot be assured.

The more general questions facing you are whether this country can afford a vigorous and extensive program in high energy physics and, if so, how many large machines it is appropriate to build and how much money should be spent on them.

It is my belief that the country can well afford a vigorous program, that the country can and should spend more money on basic research than heretofore. Such a program will make important contributions toward scientific vigor that lies behind our whole technology, will help in our efforts to educate more scientists, and will enhance our national prestige. There is certainly a limit to how many large accelerators we should build in this country and I think we may be approaching such a limit. However, the Stanford machine is unique in its characteristics and I believe should be built.

When I say that there there is a limit to the number of machines we should build, I am more concerned with the continuing operating costs than I am with the capital costs of the equipment. I want to

emphasize the importance of adequate funds for the modification and operation of the machines that we have built or are building or are planning to build. The only hesitation I have in recommending this Stanford project, with its estimated $15 million a year operating costs, is the fear that the research budgets of the AEC and other Federal agencies will not be increased sufficiently to support the increasing operation costs of these machines adequately, and at the same time continue the support of other fields than high-energy physics presently of great importance or of new areas that may later develop.

Six years from now when this machine may be coming into operation, some of the older accelerators may conceivably have reached the end of their usefulness, but for the most part we will need to keep them going full blast as well as supporting the new ones. At present the cosmotron at Brookhaven and the bevatron at Berkeley are unable to meet the demand. I anticipate that the demand will increase rather than decrease and I believe this fact should be clearly borne in mind by the committee.

Speaking more specifically to the Stanford project, it is proposed by a group of men thoroughly competent to design, construct, and operatte such a machine. They have had many years of experience; they have already built a smaller accelerator of the same type with great success. In addition to the group competent to design and build, they have some of the ablest high-energy physicists in the country who will certainly know how to make effective use of the machine once it is built.

I am very much in favor of building this machine at Stanford. They are fortunate in having a suitable site close to the campus. I think it is much better to have the machine close to the group who are most competent to build it and who must take the lead in using it than to have it at some new site or at one of the national laboratories. Much as I admire the work of the national laboratories, I am concerned by the flow of many of our ablest physicists from the universities to the national laboratories or to industry. As you know, I am well aware of the difficulties that confront a university in undertaking so large a project on or near its own campus. Yet I believe these difficulties can be solved and that it is extremely important to have some facilities of this kind at universities.

As to costs, this is the most expensive piece of research equipment I have ever heard proposed. Yet in terms of development costs or construction costs in the defense budget, it is not very large. I have made no effort to check the cost estimate, but I know you have heard expert testimony on that. Based on general experience with this type of project, I would like to see more than a 15 percent contingency, or if it is better to leave that contingency unchanged, I hope this committee will not be unduly shocked or surprised if more than $105 million is needed to complete the project.

In conclusion, let me say again that I believe this project is scientifically sound and the results will be worth the cost. It is, of course, impossible to state the value of the results quantitatively because such values cannot be measured in dollars. Perhaps the Palomar Observatory is a good analogy. I don't see how it could be proved that the results from the Palomar Observatory have justified the costs. Yet I believe most thoughtful people would agree that they have.

Surely this country can afford to spend a tiny fraction of its great wealth in probing the vastness of the stars and the minute complexities of the nucleus.

I would like to speak to four points. They have to do with the location at Stanford, that is the location of such a machine as this at a university; the question of the effect of this machine on other machines elsewhere; the costs; and, finally, I would like to come to the question of authorization of the whole of it or part of it, because of the questions that you raised yesterday, Mr. Price.

In my statement I talked about the desirability of this machine and an effort in high-energy physics in general, and I said that it seemed to me that there must come a time when we reached a limit on the number of machines that should be built and operated. I said that we might be approaching such a limit. I have heard it stated, perhaps correctly, that all groups of physicists who have or are planning or building a high energy machine think that here are enough machines of this kind around the country, whereas those who do not have access to such a machine think more are necessary.

I will now refer to my statement:

When I say there is a limit to the number of machines we should build, I am more concerned with the continuing operating costs than I am with the capital costs of equipment. I want to emphasize the importance of adequate funds for the modification and operation of machines that we have built or are building or are planning to build. The only hesitation I have in recommending this Stanford project, with its estimated $15 million a year operating cost, is the fear that the research budgets of AEC and other Federal agencies will not be increased sufficiently to support the increasing operating costs of these machines adequately, and at the same time to continue the support of other fields than high-energy physics presently of great importance or of new areas that may later develop.

Six years from now when this machine may be coming into operation, some of the older accelerators may conceivably have reached the end of their usefulness. For the most part we will need to keep them going full blast as well as supporting the new ones. At present the cosmotron at Brookhaven and the bevatron at Berkeley are unable to meet the demand. I anticipate the demand will increase rather than decrease, and I believe this fact should be clearly borne in mind by the committee.

This is the point I believe was made yesterday. I did not hear the early part of the testimony yesterday afternoon, but I think you mentioned it in talking with Dr. Williams. I know that Dr. Williams is very much aware of this problem. In the documents which I read last night—the background documents for this hearing—it is very clearly set forth. I do want to emphasize, however, that once one of these machines is built, one not only has operating costs but one has modification costs that may be very considerable. I think it would be very foolish to undertake a big machine, thinking that once the initial cost was met, that that was the end of capital costs and operating costs.

Representative DURHAM. Then in effect, Doctor, the Government is going to have to build a machine and also operate it.

Dr. SMYTH. Operate and modify it.

Representative DURHAM. Because of the fact that it is so expensive.

Dr. SMYTH. That is correct.

Representative DURHAM. There is not any college in the country that could afford to operate a machine of this kind?

Dr. SMYTH. Not conceivably.

Representative PRICE. You are referring to what may come in the future in the way of modification.

Dr. SMYTH. Yes.

Representative PRICE. What about your views on how close we will come to building this machine and putting it in operation under the present estimate?

Dr. SMYTH. I will read you what I said here, and I will add to it a little bit:

As to costs, this is the most expensive piece of research equipment I have ever heard proposed. Yet in terms of development costs or construction costs in the defense budget, it is not very large. I have made no effort to check the cost estimate, but I know you have heard expert testimony on that. Based on general experience with this type of project, I would like to see more than a 15-percent contingency, or if it is better to leave that contingency unchanged, I hope this committee will not be unduly shocked or surprised if more than $105 million is needed to complete the project.

Representative PRICE. Notwithstanding cost estimates or what we may face in the future on the cost of such a machine, do you believe and feel that it is an essential tool in our basic research program?

Dr. SMYTH. Yes; I do, Mr. Price. I would like to say with reference to costs that I think this machine has a much more solid basis for the cost estimates in terms of experience than there has been for a good many similar projects. Nevertheless, I have been burned so often that I am cautious.

Representative DURHAM. I would like to renew my question at this point that I asked the engineer a few moments ago, Doctor. You are one of the top physicists in this country and you are recognized as one. What are we going to learn from this 10-Bev. machine over and above the 6-Bev. machine?

Dr. SMYTH. Dr. Ramsey, who is the next witness, is far more qualified than I to answer that question, Mr. Durham. I can only say that historically speaking, every time we have made a substantial increase in the energy of these particles, which we use to probe the problems of nuclear structure, and the laws of force in nuclei, every time we have made such an increase we have learned a great deal. So while I do want to speak in detail about this, I am quite confident that there will be a great deal of information that can be obtained with this machine even at the initial energy, which is comparatively low—say of the order of twice the 6 billion volts—and they plan to go further. I'm sure we will learn a great deal more.

Representative DURHAM. In the future it might be a 20-Bev. machine instead of a 10-Bev. machine?

Dr. SMYTH. It probably will be. They are very conservative in their claims.

Representative PRICE. Will you continue, Doctor?

Dr. SMYTH. That I think brings me to my two other points. I wanted to speak specifically to the question of the location at Stanford. Reading from my prepared statement, I say I am very much in favor of building this machine at Stanford. [Reading:]

They are fortunate in having a suitable site close to the campus. I think it is much better to have the machine close to the group who are most competent to build it and who must take the lead in using it than to have it at some new site, or one of the national laboratories. Much as I admire the work of the national laboratories, I am concerned by the flow of many of our ablest physicists from the universities to the national laboratories or to industry. As you know, I am well aware of the difficulties that confront a university in

undertaking so large a project on or near its own campus. Yet I believe these difficulties can be solved, and it is extremely important to have facilities of this kind at universities.

The operating cost of this machine—I am now adding to what I said here—will be approximately of the same amount that the total of the two big projects that we are undertaking at Princeton will come to. Princeton is somewhat smaller than Stanford in number of students, but I think they are comparable institutions and probably fairly comparable in the normal budget. So I think I am in a position to speak to the problems that a university has in undertaking such a project. I certainly don't want to minimize them. However, I strongly believe that whenever possible research and teaching should go together. Therefore, I like the idea of having some of these machines when possible adjacent to a university. I mean really adjacent. I mean close to the university campus, and not just nominally operated by a university. It has that advantage of tying the research function to the teaching function—graduate teaching particularly—which I think is very valuable both to the teaching and to the research.

In addition to that point, we have at Stanford an unusual situation, or somewhat unusual, where the group that Dr. Ginzton was talking about yesterday has been engaged in this kind of work for many years. They have a nucleus of very able and very experienced people right there. I think they can do much better work right there than they can somewhere else.

Representative DURHAM. Doctor, doesn't this require additional facilities besides just the machine in arriving at the results? This is different from the computers that we have today. Could this machine operate without a computer system?

Dr. SMYTH. I am afraid I don't know that, or I don't know what computing facilities they have at Stanford.

Representative DURHAM. I just raise the question. It would take too much time to do it by pencil and paper. That would be out the door. I am wondering whether they have the facilities to carry out the results.

Representative PRICE. Perhaps Dr. Ginzton could comment on that. Will there be a separate computing facility with this accelerator?

Dr. GINZTON. It is precisely the point that Dr. Smyth makes that we make in our proposal that we do not wish to develop separate computing centers. We wish to be close to the university because the rest of the functions of the university could be integrated with those proposed in this project. We have a computer now, for example. It is adequate for the purposes at the moment. It may not be sufficient in the future, but it will be shared in this program with other programs.

Representative DURHAM. Is it a large one or small one?

Dr. GINZTON. It is a large one.

Representative DURHAM. Is it similar to the one at Bettis?

Dr. GINZTON. I am sorry, I am not acquainted with that one.

Representative DURHAM. I just raise the question because I don't think this includes all the costs.

Dr. SMYTH. Mr. Durham, I would like to emphasize the point that Dr. Ginzton just made. There is increasing demand in a great many

departments of the universities for computers—that is, high speed computers—it may well be that a computing center at Stanford could serve both this machine and other needs of the universities, whereas if this machine were in an isolated spot, that would be much more difficult.

Representative DURHAM. That is the reason I raised the question, because I think they go hand in hand.

Representative PRICE. Dr. Smyth, do you feel it is desirable to authorize the full amount of the cost estimate at this time, rather than to authorize only a sufficient amount to carry on design and engineering?

Dr. SMYTH. I feel very strongly, Mr. Price, that the full amount should be authorized at this time. This is a point that I did not cover in my statement, but as I said at the beginning of my testimony, I do want to talk about it. I have had some experience in the past with situations where preliminary design was authorized or research was authorized on a project, and then there was a long delay before further authorization came through. This is extremely demoralizing. It makes it difficult to assemble a staff, and once the staff is assembled, and then there is delay in further authorization, the staff disappears and it becomes extremely difficult to reassemble the staff. In this case particularly, where the design is so fully worked out in the sense of depending on components that are already in use, and where, as I understand it, a machine could be built that would be very useful even without further development of the components, I think it would be very undesirable to give partial authorization. It seems to me that partial authorization or authorization for design or research studies is appropriate when you are not sure whether the thing is going to work, and you want to have another look at it. In this case I don't believe there is any doubt about the probability of the machine working. The only doubt is how well it will work and whether research can make it work better.

Representative DURHAM. Doctor, you have one of the most important projects under your supervision, the Sherwood Project. In your opinion, would this add to research data and give you a better insight into matter?

Dr. SMYTH. Yes, sir.

Representative DURHAM. It would reflect itself in the national security and defense?

Mr. SMYTH. Eventually. I would not want to claim that I see any direct military value to this. I don't. You don't mean that.

Representative DURHAM. I don't mean that, of course. I am looking to the future.

Representative PRICE. Dr. Smyth, in your prepared statement you say that the country can and should spend more money on basic research than heretofore. In your opinion, is the present support of basic research well balanced or are there certain areas which are not receiving their proper share of such support?

Dr. SMYTH. In the areas with which I am familiar, Mr. Price, I think the balance is good. I should say, perhaps, in the general area of physics. I was talking recently with some of my colleagues, and they gave the opinion, with which I agree, that the good work in physics is for the most part being adequately supported. Of course,

we could always use more money. I think the support is well balanced and is good. Although it looks as though high energy physics was getting much greater support than other fields, it is in terms of dollars, but it just happens to be a very expensive field.

Representative PRICE. This field takes not only the mind, but the machinery and the tools.

Mr. SMYTH. That is right. A theoretical physicist or mathematician may be making just as great contribution to science as the persons who run these big accelerators, but it does not cost nearly as much. Unless he has the results that he gets from the big accelerator, he will be working in a vacuum to some extent.

Representative PRICE. Do you think of any area in basic research that you feel is not getting adequate support or that you would say should have more support?

Dr. SMYTH. Not in the field of physics, and I don't really know enough about other sicentific fields to answer that question without some study and consideration.

Representative PRICE. Do you have any further comments to make?

Dr. SMYTH. No; I think I have covered the four points that I particularly wanted to cover.

Representative PRICE. Are there any questions? If not, thank you very much, Dr. Smyth. It has been a pleasure to have you before the committee again.

Dr. SMYTH. Thank you. It is always pleasant to be here.

Representative PRICE. The next witness——

Senator HICKENLOOPER. I am sorry I had to be away from the meeting while Mr. Brobeck was finishing his testimony. Did you go into the cause of the differences in these items as set out on the comparative cost sheet? (See p. 40.)

Representative PRICE. I think we did pretty well, Senator, but if there is any particular one you are interested in, we might go into that.

Senator HICKENLOOPER. I was interested in all of them because there is a substantial variation.

Representative PRICE. We went into it, I think, pretty thoroughly, but if you would like to ask Mr. Brobeck any questions, he is still here.

Senator HICKENLOOPER. I was not clear whether they used the same data.

Mr. PRICE. Mr. Brobeck, will you come around?

Senator HICKENLOOPER. I don't mean to delay this.

Representative PRICE. Dr. Williams also is here from AEC and Mr. Ginzton is here from the university, so we may be able to resolve any questions that might arise.

Senator HICKENLOOPER. For instance, Mr. Brobeck, the Stanford University estimate on improvements to land is $1,799,000. The estimate of your company is $783,000. The AEC is $1,956,000. That is quite a discrepancy. I am not questioning the verity of the figures, but I am wondering what basis you used. In other words, we cannot get any real idea of costs if we don't use the same basic figures.

Mr. BROBECK. That is quite right. I don't know of any differences in our planning or estimating. I believe that difference is in the allocation of the cost to the different items on the list.

Senator HICKENLOOPER. On utilities the Stanford estimate is $4,862,000, the Brobeck estimate is $11,858,000—that is two and a half times or more of the Stanford estimate—the AEC estimate is $12 million plus, not quite three times as much. I fail to see where the discrepancy comes.

Mr. BBOBECK. In that case I believe the difference was that in our estimate and the AEC's, we went into considerably more detail in the design of the utilities than in the case of Stanford.

Senator HICKENLOOPER. Wasn't there an agreement as to the basic data on which these estimates could be formulated?

Mr. BROBECK. The requirements of the machine in the first two columns, Brobeck and Stanford, were the same. That is the performance of the machine as a whole. Such items as the amount of electrical power and wiring and the lengths of the runs of the cable and the number of circuit breakers, and things like that, were not worked out in detail in the Stanford estimate. In the AEC column there have been changes during the last year in the requirements of the machine. These changes such as item C as far as construction costs are concerned more or less offset each other.

Senator HICKENLOOPER. What value is this comparative table to us? I don't see any value at all to this table unless you all take the same assumptions. If your assumptions are different on various phases of this thing that is another thing. If they are different for the various estimates then it is still of no value to us. The only way I can see how any estimate of this kind, of Stanford, Brobeck Engineering Co., and AEC would be useful is if they had the same basis to work on.

Representative PRICE. Dr. Williams, would you comment on that?

Dr. WILLIAMS. Yes, sir; if you take the utilities item you were just asking about, Senator Hickenlooper, as an example, and recognize that this summary table which is before you is drawn up in the categories which are pertinent to the AEC presentation of budgets, the Stanford people working as a university did not follow that breakdown system and Mr. Brobeck and his associates came closer to it. Let us take an example in the utilities. The Brobeck estimate is $11,858,000, and the AEC is $12,042,000, not a large percentage of difference. This is made up of some items I would be happy to relate here.

Senator HICKENLOOPER. I admit those two are close together. It is probably closer than might often occur with two estimates operating even on the same basic data. I can't for the life of me see why the Stanford estimate would be $4,862,000 and both Brobeck and AEC would be almost $12 million.

Dr. WILLIAMS. Let me tell you what the Stanford people eliminated from their categories of utilities and perhaps that would help to answer that question. The substation and AEC feeders, they estimated $2.2 million, whereas both the AEC and Brobeck estimated some $7 million. This is a question of what sort of distribution should be properly put in to cover the complex as we visualize as a complete engineering system.

In the Stanford case, this cost category may well have fallen into something in the construction of the building.

In the second case on the Stanford estimate was the water supply and storage. The sewers and drains were left out of the Stanford thing. The alternating current distribution was left out.

Senator HICKENLOOPER. Why was it left out?

Dr. WILLIAMS. They were put in different categories. That is all I am saying.

Representative PRICE. Dr. Ginzton in explaining these items a short while ago said he did not consider them discrepancies, but variations.

Senator HICKENLOOPER. I don't consider them discrepancies, either.

Representative PRICE. They may turn up some place else.

Senator HICKENLOOPER. They do not turn up because the total is $79 million plus.

Representative PRICE. That difference comes from the elimination of items D and E. Dr. Ginzton, will you comment?

Dr. GINZTON. If I may use the blackboard, Mr. Chairman. First of all, there are two things I would like to say. The Stanford estimates which are listed in the Stanford proposal were prepared in 1956, and written up and presented to the Government in 1957; 1956 is an important date. Between 1956 and 1958 when the Brobeck review took place, and 1959, which is the AEC review of the estimate, certain changes occurred in the attitude toward certain objectives of the program and finally due to certain recommendations of the GAC and National Science Foundation Panels. All these things have occurred in a way which have reflected themselves in a great many ways.

Senator HICKENLOOPER. The Stanford estimate is certainly worthless, then.

Dr. GINZTON. No, sir; it is not. I would like to say there are pages and pages of detailed estimates.

Senator HICKENLOOPER. I don't mean to question the figures or the accuracy of the competence of the people who made them, but if you take a 1956 figure and add a lot more for instances to it, it would be different.

Dr. GINZTON. This is the point I would like to come to; 1956, which is the 1957 proposal, we said we would need $79 million to build this machine. In 1958, which is the Brobeck proposal, Mr. Brobeck said that our estimates were, with everything taken into account, 10 percent too low due to his more conservative approach to the problem, and due to the changes which occurred between 1956 and 1958. This added $8 million to our estimate. This is the only change between ours and the Brobeck final total. The only changes which occur in the presentation of data here are due to the fact that we excluded escalation—to a very large degree—and included nothing for contingency. These two items—which are listed as d and e—together with the 10-percent Brobeck difference over ours are the only change I can identify. The differences in the columns which are presented in the various categories are due to the fact that perhaps 100 pages of data were grouped differently by Stanford, Brobeck, and the AEC.

If you permit me to do one more thing, if you permit me to take this $116 million Brobeck estimate and the final AEC review which resulted in the $105 million, and to take out of these two numbers the research and development costs plus their share of escalation and contingency. If I subtract those two numbers—that is, engineering and their share for escalation and contingency—you find that the Brobeck proposal comes out with 94.7 million and the AEC is 95.3. This includes an analysis of hundreds and hundreds of items. This happens to be a remarkable or fortunate coincidence.

Senator HICKENLOOPER. I am not questioning the accuracy or verity of the calculations. I am trying to get straight whether or not all three groups that estimated this had the same factors in mind when they started and if they did not, why not. It does not do us any good to have a lot of variations here.

Dr. GINZTON. The estimates are based on the same machine, but over a period of 3 years there have been certain minor changes which have reflected themselves in, for example, Mr. Brobeck's increasing our estimates by 10 percent. But other than changes such as included in the 10-percent difference, we all started with the same premise; a 2-mile machine, equipped with certain research equipment, and so forth. The estimates are based on the same approach to the problem in all cases, with only relatively minor variations, and the data being presented differently. Other than that it is the same data.

Representative PRICE. I think Dr. Williams' testimony would indicate that you did not use the same factors.

Dr. WILLIAMS. The principal difference in the factors is the omission of d and e from the original Stanford proposal. The factors under consideration have changed during the time, particularly in the last year, by the reduction in the number of klystrons, as one example of a change. These changes are minor in comparison to the total. I concur with Dr. Ginzton's statement that there are no discrepancies. It is a question of order of categorization which I am sure is confusing without studying the many, many backup pages

Representative PRICE. When was the Commission estimate made?

Dr. WILLIAMS. The final Commission estimate was made in very early May following the assignment of responsibility to the AEC.

Representative PRICE. May of what year?

Dr. WILLIAMS. May of this year. These final figures in the data sheets before you were assembled in May.

Representative PRICE. When were your estimates made, Mr. Brobeck?

Mr. BROBECK. June 1958.

Representative PRICE. And yours were made in 1956?

Dr. GINZTON. Our original estimates during the fall of 1956.

Representative PRICE. The estimates that appear in this chart that we have, when were they made?

Dr. GINZTON. Completed in the fall and winter of 1956.

Representative PRICE. The Commission estimates then are the most recent estimates.

Dr. WILLIAMS. Most recent by 1 year, approximately, or later than Mr. Brobeck's firm.

Mr. RAMEY. Did you bring in an outside consultant firm on your rereview of your project?

Dr. WILLIAMS. We did not. We used our own Division of Construction and Supply as our experts.

Senator HICKENLOOPER. The only point I make, Mr. Chairman, is that if you build a house based upon a room here and here and certain accessories and utilities, and you submit it to three people based upon those assumptions, you may have a slight discrepancy, because you have that in any building that is figured. Manifestly, if you say to one estimator, we want a house of this kind, and you say to another one we want some changes in it, the figures do not do you much good.

Dr. WILLIAMS. I would again try to assure you, Senator, that there has been no basic change in the character of this so-called house. The analogies are not very exact, because it is more complicated than a house. There has been no change in the basic character of the house.

Representative PRICE. The Senator's point is very well taken. For instance, my question on the building item, No. 2, item c, I question Mr. Brobeck being $4 million under the AEC figure. He indicated it was because of the different type of construction. It seems to me that in order to get the most reasonable and accurate estimate you would know in advance what type of construction this is going to be. As of now, the engineering design has not proceeded to the point where you know exactly what type of facilities will be and what the average cost of construction will be in that area.

Dr. WILLIAMS. The AEC figures on the construction are certainly more conservative in that they anticipated costs that Mr. Brobeck did not. There are additional minor buildings, auditorium, cafeteria, and guardhouses added to the Brobeck estimate.

Representative PRICE. Mr. Brobeck said he was basing his figures on a low-cost construction. What type of building did you base your figures on?

Dr. WILLIAMS. May I ask Mr. Radley of our Division of Construction and Supply to answer this in detail because he was responsible for that figure.

Mr. H. Monroe Radley, Assistant Chief, Engineering Branch, Division of Construction and Supply, AEC. We have assumed that what you might call customary industrial construction detailing would be used for these buildings. In some cases we have added to some of the other estimates because our experience indicates that the estimates were a little low. We have one building here which is 100 feet high to which we have added quite a little money because of the extra cost. Generally you can say it is just the usual type of industrial construction conforming to AEC standards.

Senator HICKENLOOPER. Did you estimate on a different building than they estimated?

Mr. RADLEY. I have a tabulation here which explains it.

Senator HICKENLOOPER. The tabulation would not do me any good. I am not an engineer.

Representative PRICE. The point is whether you estimated on the same building.

Senator HICKENLOOPER. I am talking about whether you estimated on the same building. All I am trying to get straight is what are these estimates based on?

Mr. RADLEY. You might say substantially the same building.

Representative PRICE. You were referring to a particular building. What is your estimate on that building?

Mr. RADLEY. This large end station was $5,600,000.

Representative PRICE. For one building?

Mr. RADLEY. For one building.

Representative PRICE. Mr. Brobeck, could you find your estimate on that one particular building?

Mr. BROBECK. It is $3,384,000.

Representative PRICE. On the same building?

Mr. BROBECK. Apparently.

Representative PRICE. You are both not using the same factor. Mr. Brobeck is thinking of a lower cost construction.

Mr. BROBECK. That estimate was made by our——

Representative PRICE. This would mean materials used in the construction of the building?

Mr. BROBECK. Yes. That estimate was made by Kaiser engineers based on a detailed design of that building.

Representative PRICE. Could you tell us what the type of construction would be?

Mr. BROBECK. It was a steel frame building.

Representative PRICE. What were yours?

Mr. RADLEY. Steel frame building, concrete floor slab, and some type of siding such as corrugated asbestos, or something like that.

Representative PRICE. This is a matter of estimates. You disagree on the estimates. It is quite a disagreement.

Senator HICKENLOOPER. Let us take the tunnel. You know the length of the tunnel. Isn't that pretty well fixed?

Mr. BROBECK. Yes.

Senator HICKENLOOPER. You know the dimensions of the tunnel.

Mr. BROBECK. Yes.

Senator HICKENLOOPER. Isn't that pretty well fixed?

Mr. BROBECK. The tunnel that we estimated had additional space in it for electrical power equipment which is not included in the tunnel that Stanford estimated. We found those spaces to be necessary when the detailed layout was made.

Senator HICKENLOOPER. I understand that they had trouble with this tunnel going from here over to the New Senate Office Building.

Representative PRICE. They had no trouble with the tunnel. They could not find a way to get out.

Senator HICKENLOOPER. It is a little different from that. They started from each end where they could see each end of the tunnel and missed it by some 8 feet, I am told. You do have difficulties with tunnels, as I understand. Also they walled it up so they could not get the cars in. So those things occurred, and maybe you can say they are routine. But on this tunnel, there is a difference of $5\frac{1}{3}$ million in one estimate and $6\frac{1}{2}$ million in the other. If it is the same tunnel I can't understand it. If it is a different tunnel and a lot of things are put in it that were not included in the other, that is all I am getting at.

Dr. GINZTON. Perhaps I should apologize for Stanford suggesting the use of tunnels. The difference of these estimates is due to a very major item. The tunnels are exactly the same tunnels in terms of dimensions. The difference is that Stanford did not propose to line the tunnels with concrete. We did not think it was necessary. Further studies by Kaiser engineers indicated that for various reasons lining the tunnels with reinforced concrete would be desirable and we agreed with them. This represents an additional cost of $3 million.

Senator HICKENLOOPER. I can understand that. I am not quarreling with it.

Dr. GINZTON. Further, the Brobeck Associates in laying out the detailed plan of the tunnels showed that there was not sufficient space in the tunnels for electrical equipment, and suggested the use of additional side tunnels. These were not anticipated by Stanford. We agreed that additions of this sort made by Brobeck Associates were wise. We accepted theirs in presenting our data to AEC finally. We agreed that a substantial fraction of the cost indicated between ours and Brobeck's is due to these two factors, and we accepted the Brobeck approach as being the proper approach.

Senator HICKENLOOPER. I am not quarreling with the sincerity of these estimates. I am just saying that to submit figures here that are not based on the same thing does not do us any good.

Dr. GINZTON. They are based on the same things except that things have evolved. For example, one item, the tunnels are now proposed to be lined. This is a specific thing that developed over a period of 3 years.

Senator HICKENLOOPER. I understand that. I am not quarreling with it in the slightest degree. I do know that we have to stand on the floor and exhibit figures and these figures to me are worthless, with the exception of probably the Brobeck and AEC figures. In comparison with the Stanford figures, that will need a lot of explanation which gets into a technical field which is beyond me.

Representative PRICE. Dr. Williams, for the information of the committee, would you supply the detailed background of these figures for the record?

Dr. WILLIAMS. We can give the backup sheets for the record. We will provide the breakdown of these more summary statements.

(The information requested is as follows:)

COMPARATIVE COST ESTIMATES STANFORD ELECTRON ACCELERATOR (CONSTRUCTION)

In comparing the cost estimates prepared by Stanford University, Brobeck Associates, and the AEC several salient points must be borne in mind.

(1) The three estimates were made at different times: Stanford in late 1956, Brobeck in mid-1958, and the AEC in mid-1959. Representatives of Stanford aided the AEC in preparing its estimate and concurred in the data sheets that were presented to Congress.

(2) The three estimates were made under slightly different assumptions: The number of klystrons in AEC's estimate was reduced from 480 to 240, the number of buildings in AEC's estimate was increased, Stanford's estimate did not provide a concrete lining for the tunnel, and AEC's and Brobeck's estimates assume a larger demand for power.

(3) Stanford included no estimate for contingency and only $2 million for escalation, which accounts in large part for their estimate being substantially lower than the estimates made by Brobeck and the AEC.

(4) The AEC's estimate contemplates that $18 million will be needed for research and development. This amount should be added to AEC's estimate of $105 million when comparing the AEC estimate with the estimates made by Stanford and Brobeck since both of these estimates included this item as part of the construction costs. However, it should be noted that the amount originally included for research and development by Stanford and Brobeck totaled approximately $10 million.

[In thousands]

Item	Stanford	Brobeck	AEC	Remarks
Engineering, design and inspection	$19,171	$17,660	$7,600	The Stanford and Brobeck estimates for construction costs include research and development; the AEC estimate excludes this item from the construction costs.
Construction costs:				
(1) Improvements to land	1,799	783	1,956	
Site preparation	420	----------	568	Brobeck includes this item under tunnels.
Roads and parking	700	188	700	Brobeck did not include parking areas in this category.
Area improvements	194	280	373	Brobeck did not include landscaping in this category.
Outdoor utilities	485	315	315	Stanford did not include storm drains in this category. Some items that Stanford included here were put in the utilities category by the AEC and Brobeck.
(2) Buildings	8,610	6,534	10,500	
Laboratories, shops, offices, etc	5,802	5,352	9,260	The AEC estimate includes additional support buildings as well as higher building costs per square foot, based on AEC actual experience in this field.
Shielding	2,808	1,182	1,240	The amount of shielding necessary on this project cannot be precisely estimated.
(3) Utilities	4,862	11,858	12,042	
Electrical	2,711	8,236	8,388	Stanford does not include yard electrical utilities in this category.
Water	2,119	3,392	3,392	Brobeck and AEC made a more conservative estimate of the cooling water needed.
Miscellaneous	32	230	262	
(4) Tunnels	10,420	15,831	16,764	
Klystrons and accelerator tunnels	8,635	12,053	12,986	On the basis of available information Brobeck and the AEC strongly recommended a concrete lining for the tunnels.
Cross drifts, vents, alcoves, etc	1,785	3,778	3,778	Brobeck and Stanford estimated that more cross drifts and more room for electrical equipment was necessary in the tunnels.
(5) Accelerator	28,292	27,987	23,789	
Accelerator test section, power components and accelerator proper.	17,166	19,174	15,777	The Brobeck and Stanford estimates are based on a 480-klystron machine; the AEC estimate is based on a 240-klystron machine.
Klystrons, switchyard, controls, and instruments.	11,126	8,813	8,012	
(6) Equipment	6,417	10,785	9,600	
Research equipment	----------	4,098	4,098	
Klystron laboratory	1,364	1,235	490	AEC's estimate is lower because kylstrons were reduced from 480 to 240.
Other	5,053	5,452	5,012	Brobeck's estimate includes $560,000 for installation of equipment.

Escalation

Escalation	(1)	13,156	9,349	Stanford's estimate for escalation totaled only $2,000,000. Brobeck indicates escalation approximating 6 percent from the 2d through the 6th year; the AEC used a factor of approximately 4 percent each year.
Contingency		11,402	13,400	No estimate for contingency was included in the Stanford estimate.
Total project	79,571	115,996	105,000	

[1] $2,000,000 has been prorated to above items.

Representative PRICE. And on the operating costs also.
Dr. WILLIAMS. Yes, we will make an attempt to do that.
Representative PRICE. Thank you very much, gentlemen.
(The information requested is as follows:)

COMPARATIVE ANNUAL OPERATING COST ESTIMATES, STANFORD ELECTRON ACCELERATOR, FOR INCLUSION IN THE STANFORD ACCELERATOR HEARINGS, JULY 15, 1959

As in the case of the comparison of construction estimates, the operating estimates prepared by Stanford University, Brobeck Associates, and the AEC were made at different times and under slightly different assumptions. Furthermore, these estimate have been based on an operational year some 6 years hence for a machine to be used for experimental purposes, the operating details of which cannot be accurately predicted. Under the circumstances a complete detailed analysis of the operating costs has not been made by the Atomic Energy Commission, but rather an intermediate figure between the Stanford and Brobeck estimates has been developed.

[In thousands]

Item	Stanford	Brobeck	AEC
Machine operation and maintenance	$5,431	$5,878	$5,000
Research and research equipment	6,305	6,835	
Machine changes and improvements	875	1,375	10,000
General services and administration	1,704	2,657	
Total	14,315	16,745	15,000

NOTE.—Refer to appendix 7, page 634, for operating and electrical energy costs estimates submitted by William M. Brobeck and Associates and to appendix 9, page 641, for power cost estimate submitted by Stanford.

Representative PRICE. The next witness will be Dr. N. F. Ramsey, of the Harvard-MIT accelerator project. Dr. Ramsey.

STATEMENT OF DR. NORMAN F. RAMSEY, PROFESSOR OF PHYSICS, HARVARD UNIVERSITY

Dr. RAMSEY. Thank you, Mr. Chairman. I think Dr. Smyth in his introduction said that he was here as an unprejudiced witness. In a certain sense I would appear to be superficially a prejudiced witness who by normal standards would be prejudiced against the project. This is by virtue of the fact that I am rather well known to prefer small and inexpensive research compared to large and expensive research. Furthermore, I am associated with the Cambridge electron accelerator, which you might say is a competitor of this one, and if we can keep the competition out, we will have the field to ourselves.

However, despite this fact, as will be apparent in the statement, I am strongly in support of the present proposal and I shall explain the reasons for this.

For many years, one of the basic and most fruitful scientific studies has been the study of the nature of matter and of the particles of which matter consists. From these studies there have been immense practical applications whose value vastly exceeds the cost of the original research in the field. As examples of direct application of such research, I need only to mention the discovery and study of electricity during an earlier century and the practical development of atomic and fusion energy in more recent years. However, the indirect applications arising from the technology developed in the course of such

research have been of comparable importance. For example, the earliest digital electronic circuits that are now so widely used in computing machines, missile guidance systems, and so forth, were first developed by nuclear physicists for use in their basic research.

The basic study of elementary particles has led to the need for accelerators of increased energy and, consequently and unfortunately, of increased cost. The need for the increased energy is a direct consequence of the nature of the problem and chiefly arises from the following two characteristics: (*a*) the need for high energies to dissociate and create the various elementary particles, some of which live only extremely short times and (*b*) the necessity if using particles of very short wavelength and hence of very high energy in order to be able to explore the internal nature of the extremely small elementary particles.

In my opinion, the necessity for large and expensive accelerators is a very sad necessity which nature seems to be forcing upon scientists. For example, as a scientist I greatly regret the inevitable amount of time which so brilliant a man as Professor Panofsky will have to spend on administrative, financial, and redtape problems with the proposed accelerator. On the other hand, I can assure you that the need for high energy and expensive accelerators is an essential characteristic of the basic problems and is not merely a desire on the part of Professor Panofsky or other scientists to spend large sums of money and to operate large government supported contracts. If, for example, it were possible to manufacture an accelerator costing only $1 million instead of $100 million which would produce the same kind of basic results but merely at a 100 times slower rate, I can assure you that such an accelerator would be greatly welcomed by me, and I am sure the same would be true of Professor Panofsky. Unfortunately, however, with only present knowledge or expectations, such a less expensive accelerator would simply not produce the same kind of information at all. At high energies it is possible to create elementary particle reactions that simply cannot occur at lower energies.

If you have to produce phenomena that only occur at 10 billion volts, you have to go to 10 billion volts. If you drop down to 4 billion volts, you don't produce it at all.

Now I would like to make some comments on the general feasibility as viewed by myself of the proposal which I have studied with great interest and great care for a number of years, beginning with the 1956 proposal, and even periods before that. I am thoroughly convinced that the device is feasible. In any completely new project of this nature, it is inevitable that many of the specific and detailed plans must be altered before final construction is completed, due to new knowledge and experience gained. Several examples have already come up. There is the necessity of lining the walls of the tunnel on further detailed studies.

On the other hand, with such normal modifications in a project of this nature, I see no reason that the proposed accelerator should fail. In fact, the nature of the linear accelerator is such that although the cost is high, the device is basically simple in conception and avoids some potential difficulties which other accelerators have.

Desirability: In my opinion, the proposed linear accelerator fits in well with a rational national and international program of high energy research. At the present time there exists in operation no accelerator which is even moderately competitive with the one proposed. Most of the existing and proposed multi-Bev accelerators are for protons. Although for comparable energies electron accelerators and proton accelerators will ordinarily produce similar particles, the nature of the studies which can be carried out most effectively with the two categories of accelerators are quite different. An electron accelerator can provide information on the photo-excitation of elementary particle reactions, experimental data on the charge distribution and structure of nucleons, etc., which cannot be obtained from a proton accelerator, regardless of its energies.

Of the accelerators currently planned or under construction, the one most nearly competitive with that proposed for Standford is the Cambridge electron accelerator jointly sponsored by Harvard University and the Massachusetts Institute of Technology. This accelerator, with which I am associated, in my opinion gives promise of being an extremely interesting one scientifically. Even if the proposed Stanford accelerator were an exact duplicate of the Cambridge electron accelerator, I would welcome its construction, since we already see that one of our most difficult operating problems will be taking care of the huge demand for experimental time on this machine. However, the proposed accelerator is quite different in nature from the Cambridge one, and it is quite certain that the two instruments will complement rather than compete with each other.

It might appear logical that I should oppose the Stanford proposal since, on the completion of that project, I could no longer boast of being associated with the world's highest energy electron accelerator. On the other hand, I am convinced that the Stanford accelerator will make important contributions to science and I further believe that the two accelerators will complement each other in such a fashion that each in the presence of the other will contribute more valuable information than it would if only one of the instruments existed. The two instruments differ in many ways, of which perhaps the most important is in energy. The Stanford accelerator was initially planned for approximately 15 Bev. with the potentiality of perhaps eventually achieving 45 Bev. with the appropriation of additional funds. The Cambridge electron accelerator, on the other hand, is initially planned for 6 Bev., though with some additional future funds the energy could probably be raised to 7½ Bev. or higher. However, in no case could the energy be increased beyond 10 Bev. At energies of less than approximately 10 Bev. a circular accelerator can provide a major financial saving by virtue of the fact that each radio frequency cavity can accelerate each particle many times, since the particles pass through the cavity each time they travel around the circle. On the other hand, with electrons at higher energies, a circular machine becomes impractical due to the enormous loss of energy by electromagnetic radiation. Two electrons in going in a circular orbit are accelerated. The fact that they are accelerated makes them like a radio transmitting antenna and enormous power is lost in that form. This radiation loss is proportional to the third power of the particle energy and the first power of the magnetic field. Consequently, at energies above

10 Bev. either enormous amounts of radio frequency power must be supplied or else the magnetic field must be so drastically reduced that the circle is of such a huge size that all economic advantages of the circular machine are lost. Personally I know of no other practical way to produce electrons in the 10 to 45 Bev. energy region than with a linear accelerator that is similar to that proposed by the Stanford group.

Now, as to the question concerning which several people passed the buck to me and on which I cannot again pass it on, namely, what can be learned at 10 to 15 Bev. that cannot be learned at 6 Bev., I think the only really honest answer to that question is I don't know. That is a very exciting and interesting answer, not the reverse. The very fact that you cannot predict exactly what will occur between 6 and 7.5 Bev. and 15 or 45 Bev. is one of the important reasons you want to make the study.

Representative PRICE. Will you explain why 10 Bev. is the upper limit for the circular accelerator?

Dr. RAMSEY. Yes; if an electron is accelerated it radiates radio waves. This is at low frequency. An electron moving in a circle is also accelerated and it is going practically the velocity of light. It is 99.9999999 percent of the velocity of light. As a result of this from a relativistic calculation, it turns out that there is a large amount of electromagnetic radiation which is very strong X-ray radiation from the particles as they go around. For example, at 6 Bev. the first energy we are working for on the Cambridge machine, each time our electrons make one traversal of the circle, they radiate 4.5 million volts of energy. In other words, if we don't supply as much as 4.5 million volts to those particles each revolution, instead of being accelerated they will be decelerated. This radiation goes up very rapidly with the energy of the particle. If instead of at 6 Bev. we were, with the same machine, at 18 Bev., that is three times the energy, it would then take about a hundred times as much radiofrequency power to compensate for this energy loss.

In addition to the mere necessity of supplying power, there is also an inconvenience and an awkwardness that as the particles radiate due to this circular motion, a certain distortion of the orbit comes in. So it is harder to trap them in our focusing magnetic field. It is for this reason that certainly above 10 Bev. region it would be much more economical, in my opinion, to go to a linear machine.

Mr. PRICE. How does the operation of the two machines compare, including intensity?

Dr. RAMSEY. The Stanford machine should be about 30 times the intensity of ours. We expect to average a beam intensity of 1 microampere. I think their expectation is 30 microamperes. There are many ways in which the machines differ. Sometimes it is to the advantage of one and sometimes to the advantage of the other. For example, I think both machines will be able to provide external beams of the electrons which are one of the useful ways of making studies. On the other hand, I think there is little question that it is easier in the Stanford machine to get an external beam of electrons than with a circular one. Our electrons are trapped in a field. We have to do various tricks to get them out. In the case of the Stanford machine, they are going straight down the line, and all you have to

do is let them out at the bottom, as it were. These accelerators for different experiments will complement each other quite satisfactorily. This has been the experience on past accelerators as well.

Representative BATES. Doctor, are there any minimum limits to which the linear one can go? In other words, can it operate effectively below 6 Bev.?

Dr. RAMSEY. Yes. In the first place, they can take the beam off part way down the line. It could cover a wide range of energies. On the other hand I think the general experience from this would not encourage us to build the Stanford accelerator, say, and to cancel out the Cambridge one. In actual practice it almost always has turned out that the machines are usually spending 90 percent of their time operating at the upper limit.

Another way of saying it is that it is poor economy to have a hundred-million-dollar machine operating as a few million-dollar machine.

Representative BATES. If the situation required they could complement each other and do similar work and relieve the workload of one or another within the limited field?

Dr. RAMSEY. Very much so. One of the kinds of things which is characteristic of physics research and which I am certain we would both be doing is, for example, measurements on how various phenomena vary between 6 and 15 Bev. They will come down to 6 to see how it cross-compares with our completely independent measurements at 6, because then you have a calibration of each apparatus, and find out one or the other is wrong or each has correct results. I think to this extent they are very strongly mutually supporting.

The same is true on ideas which can originate from each machine. In other words, I think it is almost inevitable that the Cambridge electron accelerator group will think of a smart kind of research experiment which is just perfect to be done at 12 Bev. region, and I am sure likewise that new techniques will be introduced at Stanford energies which we will be just delighted to take over and will greatly increase the efficiency of our machines at lower energies.

Representative BATES. You indicated you did not know the answer to the question that awaited you. Yesterday I understood Dr. Haworth to indicate, as I recall, that the antiparticles which have been theoretically computed would undoubtedly be determined by the higher Bev. At least that was the conclusion I drew from what he said.

Dr. RAMSEY. I only got to a part of my statement on that. I think the really interesting and really important discoveries that are going to be made at the additional energies provided by the Stanford machine will be the things that we cannot predict. The very fact that we cannot predict them is why they are important.

It is also true that you can quite clearly predict a certain number of things which should be particularly relevant. For example, consider the case of the so-called cascade particles, in this case the threshold for the production of pairs of these particles is around 7 Bev. Certainly when the Cambridge accelerator is in the 6 Bev. form, which is the form initially authorized, it will not produce these at all in pairs. Even if our energy is increased to 7.5 Bev. we will produce them only in modest quantities. On the other hand, at 10 or 15 Bev.

these same particles would be produced in large intensities. The same is somewhat true to a lesser degree with the sigma particles. Dr. Haworth's answers and mine are really quite consistent. I think this is true. If we got on the side, I think we would both also agree that the real answers we are looking for are the ones we would not predict in advance. I am sure that the Stanford machine will provide much more valuable results than merely a measurement of the threshold and the production rates of the cascade particles.

Representative BATES. You don't know what the total results would be from your experiments, but you have a certain feel of certainty?

Dr. RAMSEY. It is possible to guarantee a minimum of new results that will be learned. Even the other phenomena which do not have thresholds above our energy, can be studied with interest to learn how these vary as a function of energy; this you can predict. However, I have been associated with the acelerator business long enough so that I am slightly amused when I read the reports of what will be discovered at the higher energies, because the really important discoveries are the ones never mentioned in advance.

For example, the proposal 15 years ago for producing the higher energy cyclotron at Berkeley. It would have said nothing about producing the various kinds of mesons that are produced because it was not known that you could produce them. Pi mesons were not expected to be produced. They were not known to exist. The really important payoff is the unpredictable. But there is predictable data too.

I might skip on to a brief word pertaining to costs. There I don't want to say very much. You had a group of engineers reviewing it. I do feel from looking at it myself the cost estimates have been thoroughly reviewed. They seem to be conservative. There is a relevant observation on this linear machine. I do believe it is one for which it is easier to make cost estimates than on my other kinds of accelerators. It is a more predictable nature. I think it is also true that any experimental device is a new venture and there is a certain amount of unpredictability in cost which I think has been pretty conservatively covered. However, you cannot guarantee it.

One thing I think is worth pointing out, and that is even if you do miss the cost estimate which I hope and believe you won't, in a certain sense there is not as big a net cost difference to the Government as appears to be the case. It is more a matter of bookkeeping procedures in that the actual experience, and it shows in the estimates here, of most of the high-energy accelerators, is that the cost per year of building the accelerator is quite comparable to the cost per year of operating and doing research with it.

It is also pretty general experience if the cost estimate goes up, the construction time goes up, and the time at which you start doing research goes up, and the dominant variation when there is a change in the cost estimate is actually a change at the time at which the research begins and a saving of one kind of money and a greater expenditure of another. As a matter of fact, as mentioned in the statement I think in some ways it would be an advantage, though far be it from me to suggest how the Government bookkeeping should be done, there would be some advantage if this change were a little more clearly recognized, so it would be somewhat easier to convert research

and operation money to construction money or vice versa. If, for example, it becomes apparent that things have been overly conservative in the Stanford accelerator, and it can be in operation a year earlier than anticipated, in which case it will be certainly cheaper, I think it would be helpful if they could use the last bit of construction money to get the machine in operation in a hurry. I don't want to make much of a point on this, except to point out that the net cost to the Government is rather less varied in total than in construction alone.

My only concluding remark on my own initiative was again one which has been stressed by others, and I am happy to say it again, myself. Though I vigorously do support the Stanford accelerator, this, of course, is by no means the only interesting research supported by the U.S. Government. I would hope very much, as has been urged by the President's Committee, and others, that full support be given to the accelerators already in operation, already planned, and to other research which does not have the same cost.

Representative PRICE. Thank you very much, Doctor. Are there any questions, Senator?

Senator HICKENLOOPER. You feel, professor Ramsey, that this accelerator, leaving out the question of cost entirely, will be definitely a great contribution to physics.

Dr. RAMSEY. Absolutely; yes, sir.

Senator HICKENLOOPER. Do you feel that it is a needed development?

Dr. RAMSEY. Yes.

Senator HICKENLOOPER. And in the long run over the years that this accelerator will give us answers which will be vitally needed in the development of science?

Dr. RAMSEY. I do, indeed.

Senator HICKENLOOPER. Of course, we have to balance from a practical standpoint the cost as against the anticipated results. If the reasonably anticipated results are very great, then the cost item settles itself only down to a matter of lesser significance.

Dr. RAMSEY. That is right.

Senator HICKENLOOPER. That is, whether we are throwing money away needlessly on certain gadgetry or not, the basic cost becomes insignificant as far as the overall good is concerned. From my point of view, if this is a machine that is greatly needed and will contribute proportionately to the advancement of our knowledge, then I think the cost item is comparatively a minor matter. We can spend $100 million on a battleship or a cruiser, $300 million on a nuclear carrier, which perhaps we need—I don't say we don't—but when one compares the cost of something like this with the cost of other things, we can well make the expenditure, I think, if the anticipated results seem to warrant.

Dr. RAMSEY. I think there is no question but what very important new information which cannot be gained in any other way will be obtained from this machine.

Senator HICKENLOOPER. I have just one more question. From a broad standpoint of forging ahead in science in this field of physics, do you think that this machine is essential? Would you say that it is an essential machine?

Dr. RAMSEY. I can really only answer this question 25 years from now after the machine has been completed, and I know for sure what has been discovered. But from anything I can anticipate in advance, I can say "Yes."

Senator HICKENLOOPER. I understand that. When I use the word "essential," I use it in a general way. It is essential that we have buildings in which to teach students. I suppose students could be taught under the tree if we had to do it.

Dr. RAMSEY. Yes.

Senator HICKENLOOPER. We consider it essential to have adequate equipment in the schools to teach the students. We also consider certain housing conveniences to be essential and beneficial. So, in the broad sense, do you consider that this machine is essential to the advancement of science?

Dr. RAMSEY. I do.

Senator HICKENLOOPER. I understand perfectly that you cannot predict exactly what the machine will do, but there is enough scientific knowledge so that there is a great assurance that it will contribute at least at the moment immeasurably to our understanding of the behaviors of matter and so on.

Dr. RAMSEY. That is correct.

Senator HICKENLOOPER. Thank you. That is all.

Representative PRICE. Mr. Bates.

Representative BATES. Doctor, I want to say that, like yourself, I wish this had been planned to be built in the center of the world's culture.

Representative PRICE. Thank you for those kind remarks about my district.

Representative BATES. I think you have made a very persuasive case, and I have been very much impressed by these witnesses. Do you think the plan outlined yesterday is correctly planned?

Dr. RAMSEY. I regret to say I was not here yesterday. I have been in enough conversations with the various groups concerned that I think I know what the plan would be, and I would say "Yes." I really cannot comment on that.

Representative PRICE. Doctor, your complete statement will be included in the record. We thank you.

Dr. RAMSEY. Thank you, sir.

(The statement referred to follows:)

STANFORD LINEAR ELECTRON ACCELERATOR

Statement by Norman F. Ramsey, professor of physics, Harvard University

I. INTRODUCTION

For many years, one of the basic and most fruitful scientific studies has been the study of the nature of matter and of the particles of which matter consists. From these studies there have been immense practical applications whose value vastly exceeds the cost of the original research in the field. As examples of direct applications of such research, I need only mention the discovery and study of electricity during an earlier century and the practical development of atomic and fusion energy in more recent years. However, the indirect applications arising from the technology developed in the course of such research have been of comparble importance. For example, the earliest digital electronic circuits that are now so widely used in computing machines, missile guidance systems, etc., were first developed by nuclear physicists for use in their basic research.

The basic study of elementary particles has led to the need for accelerators of increased energy and, consequently and unfortunately, of increased cost. The need for the increased energy is a direct consequence of the nature of the problem and chiefly arises from the following two characteristics: (*a*) The need for high energies to disassociate and create the various elementary particles, some of which live only extremely short times, and (*c*) the necessity of using particles of very short wavelength and hence of very high energy in order to be able to explore the internal nature of the extremely small elementary particles.

In my opinion, the necessity for large and expensive accelerators is a very sad necessity which nature seems to be forcing upon scientists. For example, as a scientist I greatly regret the inevitable amount of time which so brilliant a man as Professor Panofsky will have to spend on administrative, financial, and red-tape problems with the proposed accelerator. On the other hand, I can assure you that the need for high energy and expensive accelerators is an essential characteristic of the basic problem and is not merely a desire on the part of Professor Panofsky or other scientists to spend large sums of money and to operate large Government-supported contracts. If, for example, it were possible to manufacture an accelerator costing only $1 million instead of $100 million which would produce the same kind of basic results but merely at a hundred times slower rate, I can assure you that such an accelerator would be greatly welcomed by me, and I am sure the same would be true of Professor Panofsky. Unfortunately, however, with only present knowledge or expectations, such a less expensive accelerator would simply not produce the same kind of information at all. At high energies it is possible to create elementary particle reactions that simply cannot occur at lower energies.

II. FEASIBILITY

I have studied the proposal for the proposed Stanford accelerator with care, and I am convinced that a device of this nature is feasible. In any completely new project of this nature, it is inevitable that many of the specific and detailed plans must be altered before the final construction is completed, due to new knowledge and experience gained. On the other hand, with such normal modifications, I see no reason that the proposed accelerator should fail. In fact, the nature of a linear accelerator is such that although the cost is high the device is basically simple in conception and avoids some potential difficulties which other accelerators have.

III. DESIRABILITY

In my opinion, the proposed linear accelerator fits in well with a rational national and international program of high energy research. At the present time there exists in operation no accelerator which is even moderately competitive with the one proposed. Most of the existing and proposed multi-Bev. accelerators are for protons. Although for comparable energies electron accelerators and proton accelerators will ordinarily produce similar particles, the nature of the studies which can be carried out most effectively with the two categories of accelerators are quite different. An electron accelerator can provide information on the photoexcitation of elementary particle reactions, experimental data on the charge distribution and structure of nucleons, etc., which cannot be obtained from a proton accelerator, regardless of its energies.

Of the accelerators currently planned or under construction, the one most nearly competitive with that proposed for Stanford, is the Cambridge electron accelerator, jointly sponsored by Harvard University and the Massachusetts Institute of Technology. This accelerator, with which I am associated, in my opinion gives promise of being an extremely interesting one scientifically. Even if the proposed Stanford accelerator were an exact duplicate of the Cambridge electron accelerator, I would welcome its construction, since we already see that one of our most difficult operating problems will be taking care of the huge demand for experimental time on this machine. However, the proposed accelerator is quite different in nature from the Cambridge one, and it is quite certain that the two instruments will complement rather than compete with each other.

It might appear logical that I should oppose the Stanford proposal since, on the completion of that project, I could no longer boast of being associated with the world's highest energy electron accelerator. On the other hand, I am convinced that the Stanford accelerator will make important contributions to science

and I further believe that the two accelerators will complement each other in such a fashion that each in the presence of the other will contribute more valuable information than it would if only one of the instruments existed. The two instruments differ in many ways, of which perhaps the most important is in energy. The Stanford accelerator was initially planned for approximately 15 Bev. with the potentiality of perhaps eventually achieving 45 Bev. with the appropriation of additional funds. The Cambridge electron accelerator, on the other hand, is initially planned for 6 Bev., though with some additional future funds the energy could probably be raised to 7½ Bev. or higher. However, in no case could the energy be increased beyond 10 Bev. At energies of less than approximately 10 Bev. a circular accelerator can provide major financial savings by virtue of the fact that each radio frequency cavity can accelerate each particle many times, since the particles pass through the cavity each time they travel around the circle. On the other hand, with electrons at higher energies, a circular machine becomes impractical due to the enormous loss of energy by electromagnetic radiation. This radiation loss is proportional to the third power of the particle energy and the first power of the magnetic field. Consequently, at energies above 10 Bev. either enormous amounts of radio frequency power must be supplied or else the magnetic field must be so drastically reduced that the circle is of such a huge size that all economic advantages of the circular machine are lost. I know of no other practical way to produce electrons in the 10–45 Bev. energy region than with a linear accelerator similar to that proposed by the Stanford group.

It is not possible to say exactly what new phenomena will occur at these energies which cannot be observed at lower energies. On the other hand, this lack of knowledge is one of the things which makes the proposed accelerator particularly interesting. Only with an instrument of this nature will we be able to obtain reliably the answer to the question. Certainly, a considerable amount of interesting phenomena can be reliably predicted; for example, the proposed energies are much greater than the energies required to produce pairs of all known elementary particles. These particles should be produced in pairs or in greater multiplicity at the proposed energies and studies of the production rates should offer great interest. However, in my opinion, the most exciting new phenomenon in this energy region will be discoveries which cannot be predicted by our present low energy information. The very unpredictability of the phenomena will make the information of particularly great value.

In addition to their energy differences, the Cambridge electron accelerator and the Stanford accelerator will possess many other distinguishing features which will make one accelerator more suitable for certain experiments, while the other is more suitable for different experiments. Although we expect to have a strong external beam of electrons with the Cambridge electron accelerator, the problem of extracting the electron beam from the accelerator will be a more difficult and delicate one than in the case of the proposed Stanford accelerator where the electron beam is not normally trapped in a magnetic field and consequently there is no extraction problem. Similarly, the two accelerators will differ in duty cycle, beam focusing, energy definition, and other characteristics which will make one accelerator more useful for some categories of experiments, while the other is better for different experiments.

IV. COST

It is always difficult to make reliable cost estimates for an unprecedented new experimental device. On the other hand, it appears to me that the cost estimates for the proposed accelerator have been made as reliably and conservatively as can be done in advance. Although I am distressed by seeing such a large sum of money spent on a single scientific instrument, in my opinion the expenditure is justified. Furthermore, I see no way by which the comparable scientific results could be obtained for significantly smaller expenditure.

Although the novelty of the device necessarily leads to uncertainties in the cost estimates, I should like to point out that the uncertainty in the total cost to the U.S. Government is probably considerably less than the uncertainty in the construction costs. The general experience with high energy accelerators is that annual operating and research costs are quite comparable to the annual cost during the period of construction. Likewise, in most cases where the construction costs have exceeded expectations, the length of the construction period has been correspondingly increased, and the time at which the research and

operating expenses were required has been similarly delayed. As a result in most such cases the total rate of expenditure has altered much less than the construction costs and the effect has primarily been that the accelerator has been available at a later date for scientific research. In my opinion, it would be wise if in this and similar projects these characteristics were more explicitly recognized and if a greater freedom were provided for converting research and operating funds to construction purposes and vice versa if such a conversion appeared wise both to the project director and to the sponsoring Government agency. Since there is strong scientific pressure on the project director to complete the instrument at the earliest possible date, he will inevitably do his best to achieve the economies that result from greater speed. I believe that if such an increased freedom were given to interchange research and operating funds on the one hand with construction funds on the other in the present proposal and in other accelerator projects, there would be an increase in the speed and efficiency of the projects, significant reductions of redtape and delays, and, in the long run, important savings of Government money.

V. CONTINUATION OF OTHER RESEARCH SUPPORT

While supporting the proposed Stanford accelerator, I should like to urge the importance of continuing full support of the research programs with the accelerators already in existence and under construction, and the support of other basic research not requiring high energy accelerators. Although I believe that the proposed accelerator will make important contributions which will fully justify the enormous cost, the need for full and effective support of the various research projects already planned or in progress should be clearly recognized.

Representative PRICE. The next witness will be Dr. Rollefson, of the Midwestern Universities Research Association. I understand that you are accompanied by Dr. Symon, who appeared before our Research and Development Committee a little over a year ago, and gave us a little history of the MURA project.

STATEMENT OF DR. R. ROLLEFSON, DIRECTOR, MIDWESTERN UNIVERSITIES RESEARCH ASSOCIATION

Dr. ROLLEFSON. That is right, sir.

It is a pleasure for me, as a representative of the Midwestern Universities Research Association, to have an opportunity to give our enthusiastic support to the recommended authorization of the Stanford linear electron accelerator. The reasons for supporting this program have been so well and completely portrayed in the report of the special panel appointed by the President's Science Advisory Committee that I feel there is little of importance that I can add. However, since I have been asked for an independent statement, I shall take a few minutes to review what seem to me to be the most important points.

In our expanding knowledge of nature, the field of high energy physics constitutes one of the most interesting and exciting frontiers. Explorations to date have shown a complexity which was unexpected, but have at the same time revealed regularities which indicate that an understanding of these complexities is within our reach. There are now three rather well defined directions in which it is clear that further investigation is necessary and will be rewarding.

The first of these is in the further investigation of the numerous new particles which have been discovered during the last few years. These particles, nearly 30 in number, are produced so rarely and have such short lives that it has been exceedingly difficult to get any information about them other than that they exist. On the other hand,

since they arise from energetic interactions of the particles of ordinary matter, an understanding of their nature and interactions can hardly fail to increase significantly our knowledge of ordinary matter, in addition to satisfying our curiosity about the particles themselves. There is rather general agreement among physicists that what is needed for the study of these particles is an accelerator which will produce them in abundance, that is, a high intensity proton accelerator in the 10- to 15-Bev. range.

A second direction which is clearly marked is that of further exploration of the structure of the nuclear particles, making use of high speed electrons as probes. This will be a continuation of the work which has been begun at Stanford. It will require a higher energy electron accelerator than exists at the present time.

The third direction is that of ultra high energy interactions, with 25 or more Bev. of energy available for the reaction. This direction is indicated, not by preliminary results which show a wealth of interesting and unexpected phenomena, but by the fact that, every time in the past that interaction energies have been increased by an order of magnitude, important unexpected results have been obtained. One could call this the field of greatest risk and at the same time greatest opportunity to find something new and startling.

The proposed program at Stanford would cover the second of these three fields of investigation, that of exploring the structure of nuclear particles with what has been called a very high power electron microscope. The first field, the study of the nature of the recently discovered "strange particles" is one of the principal interests of the MURA program.

At this point I would like to say that the Stanford proposal will also be effective in this region of exploring the nature of these strange particles. As a matter of fact, the increases in intensity which they have recently made will make their machine more effective than it would have been according to the original plans. So in this particular field there is an overlap between the two programs.

The ultra-high-energy explorations could be carried out either with colliding beams of high speed particles as suggested by MURA, or by the development of more conventional one-way accelerators in the energy range of hundreds of Bev.

It has been my purpose in this short statement to point out that the Stanford and MURA programs are not competitors in the scientific sense, but will rather complement one another and will give a more complete coverage of the high-energy field than would be possible with either machine alone. In my opinion, all three of the directions I have mentioned will have to be explored. The only questions are: when, where, and how rapidly. I hope the answers will be: now, in the United States, as rapidly as our scientific resources permit.

Representative PRICE. Doctor, will you tell us something about the MURA project, and where you stand on that? Have you reached any point where you might be ready to submit a proposal?

Dr. ROLLEFSON. We are rather close to that point. At the present time we are completing the construction of an electron model which will be quite a substantial model. It will accelerate electrons to about 35 million electron volts. It will accelerate them both ways in a single ring. It will enable us to stack very high currents of electrons. This

model will enable us to demonstrate in a practical way essentially all of the features of a large proton accelerator. We expect this to be completed—we still hope—by the end of the summer. I could not guarantee that. It is about 20 feet across, just to give an indication of how large a model it is, and the magnets are exceedingly complicated so it is taking a rather long time to build it.

In the course of this work we are being supported very well as a development laboratory. It is our hope that when the developments are complete, we will be authorized to go ahead with the construction.

Representative PRICE. You state that the Stanford linear accelerator and the proposed MURA accelerator which is still in the stage of development are not competitors. Do they complement each other? What would be the main difference between the two, if there is any substantial difference?

Dr. ROLLEFSON. The Sanford accelerator uses electrons as the bullets to probe the nature of the nuclear particles. The MURA accelerator would use protons. The nature of interactions between electrons and nuclear particles and protons and nuclear particles is different, so it is important to have both types available. As a matter of fact, in one of the kinds of experiments that the Stanford accelerator can do, the one that was emphasized particularly by Dr. Haworth yesterday; that is, probing the distribution of charge in the nuclear particle, the electron is much more effective than the proton. I think it is fair to say that in producing the strange particles, the proton is more effective than the electron, especially if one can produce proton beams of higher intensity than the electron beams. So the two will do different things to best advantage.

Representative PRICE. Do you think it is desirable to approve full authorization that has been estimated by the Commission of $105 million, or do you think that it might be better just to authorize the design and engineering studies of the Stanford accelerator now?

Dr. ROLLEFSON. I agree with all the others who have testified here that it is important to authorize the whole amount. I think we of MURA have had considerable experience along this line, and we know how hard it is to attract and hold the best people when it is not sure what is going to happen.

Representative PRICE. Do you have any later information on the Russian high energy physics program?

Dr. ROLLEFSON. There are a couple of items that may be of interest. There is some evidence that they are making models of the MURA design. I mention this because the question came up yesterday, and there may have been some misunderstanding. I think the testimony yesterday was exactly correct, that there are no accelerators of large size making use of the MURA design. You perhaps have seen the release of the Soviet Embassy, on a machine using a spiral design magnet. This is the type of magnet we built in model form in 1957. It is not clear from this release how large this particular Soviet machine is. But it is quite obvious, I think, that it uses the spiral magnet that MURA introduced several years ago.

Representative PRICE. I think testimony was given on the MURA machine before this subcommittee some time ago and you talked of a colliding-beam principle. Is there any information that the Russians are experimenting with that or agree with that principle?

Dr. ROLLEFSON. Dr. Symon has talked with Dr. Veksler of the Soviet laboratories on this, and I would like to have him answer this if that is all right.

Representative PRICE. Dr. Symon, would you come forward? We are glad to have you before us again, Doctor. If you care to make a comment on the Stanford accelerator, we would be pleased to have it.

Dr. SYMON. I have no prepared statement, except to endorse the statement which Professor Rollefson made. I did have the opportunity at the Atoms for Peace Conference last September to talk with Professor Veksler, who as you know is in charge of building the 10 billion volt synchotron at Dubna. I asked him about reports that we had heard that the Russians were interested in colliding beam type accelerators, and he told me that there were two projects underway. One of them was to build an electron colliding beam accelerator, as far as I could judge almost identical with the model which is under construction at MURA. This was to be a 30-million volt two-way electron accelerator. It was being constructed, I believe, under the direction of Dr. Kolomenski who, incidentally, sent me a paper which he had written, in which he discovered apparently independently the two-way principle which was discovered by Dr. Okawa while he was working at MURA.

I am not sure of the completion date, but I gathered from Dr. Veksler that it would take a period of several years from last September to finish it.

There is another colliding-beam accelerator but I was unable to determine its character. It was a model to produce colliding-electron beams, but I don't know the principle on which it was based. It was under construction, I think, at Dubna, and if I remember correctly it was under the supervision of Dr. Petukhov, but I am not sure.

The third item is the one Dr. Rollefson mentioned, there is apparently a spiral sector cyclotron which has been constructed, according to the news release.

Representative PRICE. Thank you very much, Doctor.

Are there any questions? If not, thank you very much gentlemen. We are glad to have your testimony.

That will conclude the public hearings on this proposal. In closing I would like to thank the witnesses from the AEC, Stanford, and the other universities for their cooperation in this hearing. I would like to thank Dr. Welton, who heads the Oak Ridge Laboratory project, who acted as the consultant for the staff of the Joint Committee in preparing the hearing. Thank you. That concludes the public hearing.

(Thereupon at 12:10 p.m., Wednesday, July 15, 1959, the hearing was concluded.)

(Refer to app. 8, p. 640, for a letter dated July 15, 1959, from T. H. Johnson, vice president, Raytheon Manufacturing Co., commenting on the proposed Stanford accelerator.)

(Also see app. 14, p. 648, for correspondence between the Commission and the committee on the subject of patents and royalties for accelerator components.)

APPENDIXES

APPENDIX 1

U.S. ATOMIC ENERGY COMMISSION.
Washington, D.C., July 2, 1959.

Mr. JAMES T. RAMEY,
Executive Director,
Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. RAMEY: The enclosed background material on high energy physics and the Stanford accelerator proposal may be of use to members of the Joint Committee in connection with the forthcoming hearings on S. 2073 and H.R. 7464.

Sincerely yours,

A. R. LUEDECKE, *General Manager.*

Enclosures:

Report of the Advisory Panel on High Energy Accelerator dated 10/25/56.
Supplement to the Report of the Advisory Panel on High Energy Accelerator dated 9/11/58.
Linear Electron Accelerator Construction Projects Data Sheet (see p. 4).
Correlation Guide on Two-Mile Linear Accelerator, p. 273.

(NOTE.—The Stanford Proposal of April 1957 (p. 283), the Brobeck Review of the Stanford Proposal of June 1958 (p. 427), which was referred to in the Correlation Guide are also included in this appendix.)

REPORT

of the

ADVISORY PANEL

on

HIGH-ENERGY ACCELERATORS

to the

NATIONAL SCIENCE FOUNDATION

National Science Foundation
Washington 25, D. C.
October 25, 1956

FOREWORD

The National Science Foundation Advisory Panel on High Energy Accelerators was established in response to requests from the Department of Defense and the Atomic Energy Commission for a review of the status of the high-energy nuclear accelerator situation in the U. S. It was felt that this review should be made by a group consisting of nuclear physicists with extensive experience in accelerator design and construction, physicists with special competence concerning the research potentialities in the high energy field, and physicists familiar with the broad field of physics. The panel met September 10, 11, 12, 1956 at the National Science Foundation and their report with observations and recommendations was submitted to the Foundation on October 25, 1956. It is believed that this report will be of value to all who are interested in the support and progress of research in this important field.

The membership of the Advisory Panel was as follows:

L. J. Haworth, Brookhaven National Laboratory, Chairman
S. K. Allison, University of Chicago
E. J. Lofgren, University of California, Berkeley
W. K. H. Panofsky, Stanford University
I. I. Rabi, Columbia University
A. Roberts, University of Rochester
F. Seitz, University of Illinois
R. Serber, Columbia University
M. White, Princeton University
J. H. Williams, University of Minnesota
J. R. Zacharias, Massachusetts Institute of Technology

For part of the discussion period the Panel invited representatives of the Atomic Energy Commission (AEC), Department of Defense (DOD), and the National Science Foundation (NSF) to join the Panel. The AEC was represented by Dr. Thomas H. Johnson, Dr. Erwin F. Shrader, Dr. Donald Gilbert, and Dr. Charles E. Falk. The Office of the Assistant Secretary for Research and Development was represented by Mr. Earl G. Droessler, and Mr. Harry Harrison. The Air Force was represented by Lt. Col. James O. Vann, Col. Herbert F. Gagne, Dr. William J. Otting, and Mr. Raymond Heer. The Navy was represented by Dr. Randal M. Robertson, Dr. Shirleigh Silverman, and Dr. William E. Wright. The Army was represented by Dr. James B. Edson, and Lt. Col. James E. Hebbeler. The NSF was represented by Dr. Paul E. Klopsteg, Dr. C. E. Sunderlin, Dr. Raymond J. Seeger, Dr. J. Howard McMillen, and Dr. Robert R. Brown.

Alan T. Waterman
Director

REPORT OF THE ADVISORY PANEL ON HIGH-ENERGY ACCELERATORS TO THE NATIONAL SCIENCE FOUNDATION

I. INTRODUCTION

The subject of ultrahigh-energy accelerators has been reviewed in the light of developments since the Panel Report of May 2, 1954. Among the important developments are: (a) the establishment of contact with Soviet scientists, (b) the accumulation of experience in the multi-Bev range at the Cosmotron and the Bevatron, (c) the development of the fixed field alternating gradient principle, and (d) various, as yet unexplored, suggestions of additional methods of particle acceleration. During its deliberations the Panel met with representatives of interested Government agencies who reviewed their respective programs and plans. The Panel wishes to make the following observations and recommendations, including many drawn from the previous report.

II. OBSERVATIONS ABOUT HIGH-ENERGY PHYSICS

Significance of High-Energy Physics Research

High-energy physics research is at this time one of the most challenging activities with respect to both its technology and its central importance in basic science. Its pursuit is necessary to an understanding of elementary particles which is, in turn, necessary to any real understanding of atomic nuclei. A great variety of new particles with most interesting properties has been discovered. These particles seem to have a set of complicated interrelationships, as yet but vaguely understood, to which are due the stability and other properties of atomic nuclei. It is not yet clear whether still other particles remain to be discovered.

The importance of the field is perhaps best shown by the number of able scientists now working in it, both in this country and abroad. This represents a judgment that the field is both important and fruitful for basic science. The correctness of this judgment has been demonstrated by the results from the high energy accelerators now in operation. A need for increasing the available facilities is demonstrated by the great demand for bombardment time at the two existing multi-Bev accelerators. Even though multi-Bev physics is barely three years old, there is already a several-years backlog of important experiments awaiting time on the accelerators. It is clear that this situation will become worse, even taking into account new machines now under construction.

In addition to the direct scientific results, programs in this field yield many indirect technical benefits. Indeed, several developments have led directly to new instruments and equipment of importance to industry and government in completely different scientific and technological fields.

Present Position of the U. S. A.

During recent years high-energy physics has become more of an international activity, as documented in Appendix 2. The number of high-energy installations abroad has increased significantly, notably in the USSR. Although at present the United States is leading in the number and diversity of its facilities and in the productivity of its research programs, the rate of Soviet progress has been such that this situation may not persist through the next decade. The peak energy of the high-energy machines will seesaw between the Soviet and Western installations; more importantly, the apparently unlimited government support and the high rate of production of qualified technical people of the Soviet educational system will contribute to relative enhancement of the Soviet position.

The great scientific interest in and the prestige that attaches to this field of research makes it important for the United States to maintain its present position of leadership. This leadership can be preserved best by maintaining a strong, well-balanced program rather than by adjusting the details of the work to specific developments abroad.

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Cost of the National Program in High-Energy Physics

High-energy physics research is exceptionally expensive; indeed, it is almost uniquely so in all the domain of pure science. The basic reason lies in the nature of the fundamental atomic particles. To produce and study most of these requires very high accelerating potentials that can be achieved at present only by large and costly equipment. To high initial investments must be added continuing costs, for operation and research and for improvements, that can be expected to duplicate the initial expenditures every two to four years. Both the initial construction costs and those resulting from operations and from capital improvements are too great for educational institutions and other private research organizations to provide primarily from their own funds. In consequence, intensive work in the field is made possible only by major Government support.

The increased complexity and expense of major high-energy facilities make it mandatory to devote an increasing amount of time and effort to preliminary studies and design activities in order to assure economical and efficient results. The magnitude of the effort required to initiate such new technological advances is so large as to necessitate comprehensive long-range programs, supported by long-term budgets, leading from the initial conception, through a series of re-evaluations, to the possible end-result of a construction project.

Thus the development, design, and construction, as well as the effective utilization of the more advanced machines require large staffs of highly qualified, full-time scientific and technical specialists in numbers well above the normal staffs of most institutions. Such requirements result in definite limitations on the number of institutions where the most advanced programs can be located. There is, therefore, a definite limit to the number of well-considered proposals that can be expected.

If individual proposals by qualified groups be considered carefully in the light of criteria discussed later, and no overall limit is set, it is estimated that by 1962 construction of two to five machines in the 3- to 12-Bev range and one or two studies and possibly construction projects in the range above 12 Bev would be committed. This would increase the annual rate of expenditure from a presently committed $40 million per year to an estimated $60 to $90 million per year by 1962 (in terms of 1956 dollars). It includes an allowance for new construction, anticipated capital improvements, operation, and research associated with machines authorized.

We do not extend our estimates beyond 1962 because either the state of this branch of physics or accelerator technology may have changed in an important way by that time. We believe, however, that the pressure for increased expansion of effort in the field will not continue indefinitely.

Question of Diversified Support

High-energy physics, as any other branch of science, will benefit, if its support is diversified in the sense that several agencies, motivated in somewhat different ways, provide funds and contracts for construction, operation, and experimentation. In turn, the individual agencies will benefit from their direct contact with the work. Each agency has an important direct and specific interest in the science and technology of this field as well as a responsibility for maintaining the overall strength of this country in basic science. We believe that the scientific staff of each agency will benefit by being cognizant of activities in this field and will reflect the experience acquired into more effective work in the other activities of the agency.

III. PANEL RECOMMENDATIONS

In view of these facts the Panel recommends that:

1. The Government continue active support of high-energy physics, including the design, construction, and operation of and experimentation with high-energy accelerators.

2. The Department of Defense, the Atomic Energy Commission, and the National Science Foundation, which have important responsibilities for the promotion or utilization of science and technology, each engage directly in the support of high-energy physics; in particular, that the Department of Defense and the National Science Foundation extend their support in this field to maintain important positions.

3. Adequate support be given to existing research programs in this field.

4. Planning for the support of high-energy accelerators anticipate an annual rate of expenditure in this field of $60 to $90 million per year by 1962; large as it is in comparison with national nuclear research budgets of a few years ago, this rate nevertheless is believed necessary to maintain a program adequate to our national needs.

5. The need for accelerators of a variety of characteristics be recognized. The most important parameters are energy, intensity, and kind of particle. In situations where a choice is to be made, it is usually better to extend the range of these important parameters than to increase the number of functionally similar accelerators.

6. Adequate support be given to research and development pointed toward new types of accelerators. It is especially recommended that efforts be made to continue to extend the energy limit.

7. No fixed general policy be made with regard to the location of new accelerators at individual universities, national laboratories, or other research establishments; but that each proposal be reviewed on its merits with due regard to the research that will be done, the stimulation to science, and the opportunities for training.

IV. IMPLEMENTATION OF RECOMMENDATIONS

The following observations may be helpful in the implementation of the foregoing recommendations:

Support of Existing Accelerators

In emphasizing the need for additional accelerators, we do not mean to lose sight of the urgent need to strengthen the support of existing accelerators. The costs of a high-energy research program can be grouped into the 'continuing' and the 'unusual'. Among the continuing costs are the operating and maintenance costs of the accelerator proper, the cost of the research program proper, and the cost of general services. Among unusual costs are items, such as (a) large scale improvements of the machine proper, such as extention of its energy, additional shielding, modification of research space, and beam extraction, and (b) single research instruments of high unit cost. It should be noted that the need for such unusual costs usually reflects experience gained from successful prior operation of the accelerator, and cannot be foreseen intelligently at the time of design of the accelerator.

Important Accelerator Parameters

The attainable energy is not the only parameter defining the utility of a machine in high-energy physics. Among other machine properties differentiating the various machine types are (a) type of particle accelerated, (b) beam geometry, such as beam diameter, divergence, and purity, (c) duty cycle and pulse length, (d) beam intensity, and (e) ease of shielding. The design of experiments, the information derivable, and in particular the data rate achievable are highly dependent on these parameters. Experience has shown that progress in physics depends both on exploratory experiments at high energy and low data rate (and therefore, in general, of poor accuracy), and on quantitative measurements at high intensity. Appendix 3 lists the various parameters of the machines constructed. It is clear that an optimum program would demand that the energy as well as other machine parameters be chosen to achieve a large degree of diversity.

Criteria for Support

All proposals for major support of high-energy facility studies, design, and construction programs should be subject to intensive review and analysis by the staffs of the Government agencies and by groups of experts in the field. Criteria of importance are:

1. Need for the particular facility in the national high-energy program in existence and in prospect at that time.

2. Qualifications of the scientific personnel making the proposal.

3. Strength of support available from the institution making the proposal.

4. Anticipated research productivity in relation to the expenditure of money and manpower.

5. Contribution to the training of scientific and technical personnel.

6. Assurance of administrative arrangements which permit easy access by competent scientists from other organizations; geographical proximity to such scientists.

Need for Accelerator in the Mid-West

It is regrettable that no multi-Bev accelerator in operation or under construction is readily accessible to the large numbers of competent physicists in the Mid-West. It is important that this deficiency be remedied by appropriate facilities.

Development Studies

The development of plans for a machine of new design is in itself a costly undertaking which has, however, independent value. Frequently, the institution where such development is centered is not able to carry the costs for developing such plans without outside support. For this reason, we believe that serious consideration should be given to proposals for support in any of the following categories:

1. Theoretical and experimental studies in new methods of particle acceleration.

2. Studies on technological problems bearing on accelerators and their utilization.

3. Design studies on specific accelerator programs, including model tests, which would lead to a formal proposal for construction.

4. Proposals for specific accelerator construction.

Studies of New Accelerator Methods

There may be new methods of accelerating particles based on cooperative phenomena, such as plasma effects, and the self-magnetic fields of circulating beams. These possibilities were pointed out at the 1956 CERN Symposium by some members of the Soviet group; similar possibilities had also been pointed out by physicists in this country and in Great Britain. It is premature to say whether a practical accelerator will come out of this work. Pursuit of studies along these lines would, however, be worth while both because they might lead to the possibility of inventing a new and useful type of accelerator--e.g., one that would extend the practical energy limit--and because they might have value in other fields. There is, however, no real hope that some new invention will come along that will reduce the expense of high-energy nuclear physics by a large factor since a large fraction of both the construction and operating costs goes into components and services that are independent of the accelerator itself.

Training of Scientists

There is an intimate connection between high-energy machines and the training of young scientists and technical personnel. Work in this field gives specialized experience in research aimed at possibly the central question of physics today, and training in the application of the new techniques developed. Possibly no other field offers as good a demonstration of the intimate interrelation between science and engineering.

The training offered by high-energy installations falls into the following categories:

1. The training of graduate students under appropriate supervision.

2. The post-Ph.D. training of young research people to broaden their experience prior to assuming larger responsibilities.

3. The training of engineering personnel in advanced techniques useful to industry.

It should be noted that the training function of these machines partly offsets the manpower drain imposed by their construction, e.g., at present more than 100 students per year receive their Ph.D. degrees on research problems involving nuclear machines.

Despite the obvious training value of these machines, the large investment and operating cost of the most advanced machines make it difficult for a student to take a major responsibility for a research problem at the largest machines; rather his

role there must be that of assistant to the more experienced research personnel. The closest relation between student and instructor and the best experience for the student in the planning of a research project is obtained primarily in activities not involving the most expensive instruments.

Requests for Support

Projects involving major accelerator construction may originate in very different ways. At one extreme, a project evolves from a new idea in accelerator technique; such a project is necessarily associated with the person or group originating the idea. At the other extreme is the desire to place expanded accelerator facilities at a given laboratory, university, or other institution; in this case the question is posed: "What accelerator will best fit the needs if placed at - - - -?" This desire can arise from the scientists who wish to use the accelerator in the future or from decisions based on considerations of institutional or regional need.

There is ample evidence that accelerator activities generated by either method have led to successful high-energy physics research; there is no reason to doubt that this will be true in the future, since there is a large unsatisfied need for high-energy research facilities.

However, if the total number and sizes of well-justified requests exceed the bounds of possible support, then care must be taken that the selection of proposals is not such as to prevent scientific and technical advances. Any limitation on the number of institutions participating in high-energy physics research will reduce the total rate of progress in the field; to prevent the technology from extending the range of important parameters (energy, current, and kind of particle) would eventually deny access to an entirely new field of inquiry.

Table I outlines the steps in accelerator construction that appear logical to the Panel from the technical point of view. Existing and fully authorized accelerators in the U. S. are included. (A complete list, including those outside the U. S., is given in Appendix 2.) We believe that, if the program for new machines must be limited, first priority should be given to those programs which give early promise of extending the important accelerator parameters to new ranges--electron accelerators in the 15 Bev region or above, high intensity proton accelerators at approximately 6 Bev and above, and developments intended to extend appreciably the available proton energies. Machines for these purposes need extensive engineering development, orbit studies, or models (cf. Table I) before construction can begin. The next priority should be given to construction of machines that will provide badly needed increased facilities in fields of proven fruitfulness and that can be built more rapidly than can those of first priority; these include low intensity proton accelerators at energies above 6 Bev and high intensity machines below 6 Bev.

Future development on the basis of a scheme such as this would represent a plan for assuring scientific progress on a broad front in reasonable steps. Beyond this, there is certainly reason to consider additional installations which in the sense of this list are duplications; their jusitification would rest on the need for an overall rate of progress, as well as the importance of the accelerator facility to the particular institution or region in the light of the national picture.

We present this table and statement of priority in case budget problems may require choices among otherwise well justified alternatives. We suggest that this table be reviewed carefully and point out that in time such ordering will necessarily require modifications. In particular, once a high-current machine in a given energy range has become possible at comparable cost to a low current machine, the merit for the low current machine will become very small.

Respectfully Submitted,

S. K. Allison, University of Chicago
E. J. Lofgren, University of California Radiation Laboratory
W. K. H. Panofsky, Stanford University
I. I. Rabi, Columbia University
A. Roberts, University of Rochester
F. Seitz, University of Illinois
R. Serber, Columbia University
M. G. White, Princeton University
J. H. Williams, University of Minnesota
J. R. Zacharias, Massachusetts Institute of Technolgy
L. J. Haworth, Brookhaven National Laboratory, Chairman

TABLE I.--Accelerator types tabulated by energy, current, and type of particle. The intensity comparisons are more or less line by line and, in general, decrease with increasing energy, particularly in the magnetic machines. (See Table III.) Presently authorized U.S. accelerators are identified in terms of the institution where the work is carried out; tentative completion dates of machines under construction are given in brackets.

Approx. Energy (Bev)	PROTON		ELECTRON	
	'High' Current	'Low current	'High' current	'Low' Current
~1	Linear accelerator or Cyclotron	Synchrocyclotron (Univ. California) (1956)	Linear accelerator (Standford) OPERATING	Synchrotron (Cornell).....OPERATING (Calif.Inst.Tech.)OPERATING
3	High-intensity synchrotron (Princeton-Penn.) (1960)[1]	Synchrotron (Brookhaven) OPERATING	.....	.....
~7	Fixed-field alternating[2] gradient synchrotron	Synchrotron (Univ. California) OPERATING	.....	Alternating-gradient synchrotron (Harvard-MIT) (1960)
~15	Fixed-field alternating[2] gradient synchrotron	Synchrotron	Linear accelerator[3]	.....
~30	.....	Alternating-gradient synchrotron (Brookhaven)(1960)		.....
100-200	.....	Alternating-gradient synchrotron STUDY	.....	.....
~500	.....	Colliding beam STUDY[4]	.....	.....
Energy Equivalent		(very low current)		

([1])The Princeton (weak focus) synchroton is expected to deliver an average current of approximately 5×10^{-7} amperes, which, although "high" compared to that of the Brookhaven Cosmotron ($\sim 10^{-8}$ amperes) is "low" compared to the potentialities of other machines in that column (See Table III).

[2] Preliminary steps including working prototypes will have to precede these accelerators.

([3])Extensive engineering development is required.

([4])Design of machine of this type would have to be based upon the success of single high intensity FFAG accelerators. (See Appendix 3)

APPENDIX I

SIGNIFICANCE OF HIGH-ENERGY PHYSICS

The main advances in the understanding of physics come in rare large steps, such as Newton's mechanics and Einstein's relativity. The last such step was the development of quantum mechanics. At present we are facing a situation which seems to indicate and demand another major advance in our understanding of the physical world.

Quantum mechanics was able to explain in great detail the building up of an atom from its constituent nucleus and electrons, and, less completely, the building of the nucleus from its particles. It left unanswered the question of the nature of the particles themselves, and this question remains the central problem of physics today.

The work which has been done with cosmic rays and high-energy accelerators in the last few years has not solved this problem, but rather has greatly developed and enlarged it, by demonstrating the extraordinary richness and multiplicity of the system of seemingly basic particles. Most of the newly discovered particles were not foreseen by any existing theory.

A true advance in our understanding of the nature of elementary particles is not yet in sight; our knowledge of them is in fact still fragmentary. High-energy accelerators are the primary tools for acquiring such knowledge; this is a major reason for the importance of such machines to physics today.

A SYNOPSIS OF HIGH-ENERGY PHYSICS

Experimentation on synchrocyclotrons of energies up to 400 Mev led, first, to information on the forces between nucleons, and to models describing the interaction between high-energy nucleons and nuclei. It became clear that the nuclear force problem depended for its understanding on a knowledge of the more fundamental interaction between the mesons and nucleons. Further investigations determined the properties of the π-mesons and their scattering by nucleons. Simultaneously information about mesons, especially their electromagnetic interactions, was being obtained with synchrotrons.

Cosmic-ray evidence proved the existence of a variety of strange particles, both heavy mesons and heavy nucleons. The unique identification of these particles (including the discovery of new ones) and studies of their properties have been proceeding rapidly with the aid of the Cosmotron and Bevatron. The information is largely preliminary and incomplete. A limited sort of ordering and understanding of the new particles has been based on general symmetry properties, most successfully, the conservation of isotopic spin. There has been active speculation on the role of other symmetries, such as charge conjugation and parity.

The multi-Bev machines have also extended the nucleon and π-meson scattering work to high energy. This has stimulated significant theoretical advances in the treatment of meson field theory. The multiple production of π-mesons which was expected, but not described, by the theory was also observed.

Experiments on the Stanford linear accelerator gave information on the size and structure of nucleons, an advance made possible by the ability to probe small distances by the use of very energetic--and therefore short-wavelength--electrons.

The Bevatron demonstrated the existence of the anti-nucleons, and confirmed the hypothesis of charge-conjugation symmetry. Further experiments indicated anomalous interactions of these particles with ordinary nucleons, raising a whole new set of questions.

There is no basis on which to judge whether additional new particles would be discovered by still higher-energy machines. There is not even a conviction that this would be the most interesting phenomenon that might appear. Phenomena which can be anticipated, and whose analysis would have an important bearing on our present questions, are the multiple-production processes of all types of known particles. A general principle indicates that investigation of shorter and shorter distances (possibly to the point where this concept might lose meaning) requires shorter and shorter wavelengths, and thus higher and higher energies. The limitations of fundamental concepts such as that of space, or of well-established theories such as electro-

(See Appendix 3)

dynamics, can be sought in the high-energy domain.

It has only very rarely been possible to predict the field where an accelerator installation will have its maximum impact. The rate of progress of this field, on the one hand, and the difficulties of machine technology, on the other, have been so great that almost always the scientific picture has changed significantly during the time of construction of an accelerator facility. We must consider the foregoing outline of the areas which might be explored in the energy region above that presently accessible as illustrative only. The main justifications for further exploration are our ignorance as to the source from which a solution to our present incomplete understanding would originate, and our past experience of the richness of this field in terms of new phenomena.

APPENDIX 2

STATUS OF MULTI-BEV ACCELERATOR ACTIVITIES

At this time there are only two accelerators in regular operation as physics research tools at energies well above 1 Bev; both of them are located in the United States--the Brookhaven Cosmotron (3 Bev protons) and the Berkeley Bevatron (6.2 Bev protons). These machines are carrying on intensive research programs of unusual productivity, but the demand for operating time exceeds the capacity of these machines by a large factor. One of the reasons for this demand is that the energy of these machines overlaps the lower energy range of cosmic rays and the intensity and other factors are so much more favorable that many physicists have shifted their interest from cosmic rays to accelerator physics.

In addition to these two machines operating well above the 1-Bev figure, several presently operate at energies near 1 Bev--the Birmingham proton synchrotron (900-Mev protons, UK), the Cornell synchrotron (~850-Mev electrons, USA), the Bolshoya Volga synchrocyclotron (680-Mev protons, USSR), the Stanford linear accelerator (~650-Mev electrons, USA), and the synchrotron at the California Institute of Technology (6 Bev electrons, USA). The University of California proton synchrocyclotron is approaching operation in this region after being rebuilt to increase its energy.

As a result of the successful operation of the above machines, in combination with the unusual interest of the results obtained and the obvious shortage of available operating time, many additional installations are under construction, in design, or being considered. A list of such activities follows. This list, Table II, includes machines for which the completion date can be estimated; machines for which the parameters are fairly definitely established, but which have not been commited for construction; and thirdly, studies being carried out where even the machine type has not been determined. Although activities 'under consideration' have been included, the list cannot hope to be complete in this respect.

This table documents the intense and international interest in the field of high-energy physics and indicates the need for extensive communication. In addition to comparing the status of various accelerators, it might be instructive to compare methods, design principles, administrative procedures, etc., in various countries with the hope of learning possible improvements.

Among observations concerning operations in different countries one might list:

1. The existence of large cooperative laboratories (CERN, Geneva; Brookhaven National Laboratory, U.S.) has not made multi-Bev installations unnecessary at collaborating institutions but has stimulated them.

2. The high-energy program in the United States is distinguished by the wide distribution and diversity of interest of its centers.

3. The high-energy installations in the USSR are in general witness to the following facts: (a) nearly complete disregard for economy of construction and emphasis on rapid construction schedules; (b) quick administrative decision in the initiation of activities in this field.

We are impressed by the speed with which the Soviet effort in this field is progressing. At this time the United States is leading in high-energy physics, both as to number and diversity of facilities as well as to the total productivity and originality of the research program. However, the Soviet work in this field appears to represent an all-out effort, and is backed by apparently unlimited government support; in particular, the quality and quantity of physicists and engineers involved in the program is very high. These facts, in combination with the high rate of production of qualified technical talent of the Soviet educational system, cause us to believe that the Soviet and United States positions in this field will become comparable in the next decade.

TABLE II.--Multi-Bev Installations Under Construction, in Design, or Under Consideration

Machine	Particle	Energy	Location	Status Status	Expected Completion
Alternating-gradient synchrotron....	proton	25 Bev	Brookhaven Nat'l Lab. (USA)	Construction	1960
Alternating-gradient synchrotron....	proton	25 Bev	CERN (Switzerland)	Construction	1960
Alternating-gradient synchrotron....	Proton	50 Bev	USSR (site not chosen)	Study	1961
Alternating-gradient synchrotron....	proton	7 Bev	USSR (site not chosen)	Design	1959
Synchrotron.....	proton	10 Bev	Bolshoya Volga (USSR)	Construction	1956-7
Synchrotron.....	proton	2.5 Bev	Saclay (FRANCE)	Construction	1958
Synchrotron.....	proton	3 Bev	Princeton-Pennsylvania (USA)	Design	1960
Synchrotron.....	proton	10 Bev	Canberra (Australia)	Construction	~ 1960
Synchrotron (air core, low rep. rate)	proton	1.5 Bev	Rome (Italy)	Construction	1959
Synchrotron.....	electron	1 Bev	Stockholm (Sweden)	Construction	1959
Synchrotron.....	electron	7 Bev	Harvard-MIT, Cambridge (USA)	Design	1960
Synchrotron.....	electron	2 Bev	Paris (France)	Construction	1958
Linear accelerator.....	electron				
Synchrotron.....	proton	15 Bev	Argonne Nat'l Lab. (USA)	Design	....
Two 15-Bev colliding-beam fixed-field alternating-gradient synchrotrons.....	proton	530 Bev Equivalent	MURA (USA)	Study	....
Alternating-gradient synchrotron....	proton	6 Bev	Univ. of Rochester (USA)	Study	....
Linear accelerator.....	electron	15-45 Bev	Stanford Univ. (USA)	Study	....
Synchrotron.....	proton	6-8 Bev	AERE-Harwell (UK)	Design	....

Multi-Bev accelerator studies: Oak Ridge Nat'l Lab. (USA); Univ. California (USA); Carnegie Inst. Tech.(USA); Univ. Washington (USA); Los Alamos Scientific Lab. (USA); National Research Council (Canada); Hamburg, (Germany)

APPENDIX 3

TYPES OF ACCELERATORS AND FUTURE LINES OF DEVELOPMENT

An accelerator is intended to produce a beam of high energy particles, usually protons or electrons. To perform an experiment, this beam, is directed against a target. The experiment may consist of observing the secondary particles produced in the target; such experiments include those on the production and properties of K-mesons, hyperons, and anti-nucleons. Accelerators that produce well-defined beams, homogeneous in energy, with a useful duty cycle, and preferably outside the accelerator (external beams), are desirable for such experiments. If the intensity of the accelerator beam is sufficient, the secondary particles produced may themselves constitute a beam whose interaction with a secondary target can be studied; such experiments are extremely valuable in elucidating the nature of the particles produced.

New developments in accelerator technology are of primary importance if they extend the range of energy or intensity available for experiment. Other factors of secondary importance are duty cycle, beam geometry, and so on. Since increases in energy lead us into hitherto unexplored areas, they are perhaps the most important single line of advance.

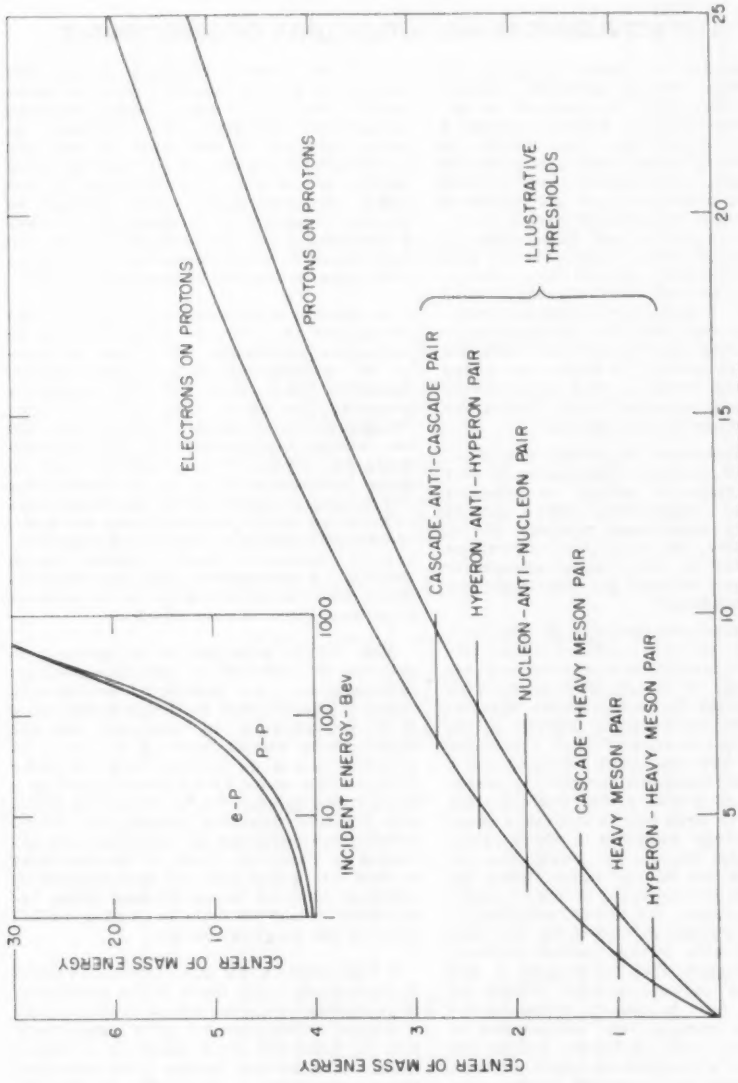
An important consideration is that in a collision between two particles the variety of possible interactions is determined, not by the energy of the incident particle as measured in the fixed laboratory system, but rather by the available energy in the center of mass system. Figure 1 plots the relationship between these energies for a system of one fixed and one moving proton and another of a fixed proton and a moving electron. It is seen that to achieve a given available energy requires a significantly higher incident energy--in a ratio that increases with the energy scale. When the target proton (or neutron) is bound within a complex nucleus, the situation is altered by internal (Fermi) motion of the nucleons and the available energy varies statistically. The figure also illustrates a few thresholds of current interest. There is, of course, a host of others, extending indefinitely in energy, that correspond to various multiple particle production processes. In a complex nucleus the effective thresholds are lowered appreciably (e.g. ~15% at 6 Bev) by the Fermi motion.

It is seen that to increase the available energy by a large amount over machines now in construction would require very high accelerator energies. For example, an accelerator of 100 Bev would be required to achieve 12 Bev of available energy in the center of mass system. Energies of this order, or even higher, may perhaps be reached directly by building much larger accelerators of "conventional" kinds, but they would be very expensive. Other possible approaches will be mentioned later.

Increases of intensity also lead us into unexplored territory by making events or processes observable which are too rare to be investigated with weaker beams; therefore they must also be vigorously pursued. The most important recent development in accelerator technology, and one whose implications are not yet fully explored, would, if successful, lead to large increases. This is the fixed-field alternating-gradient (FFAG) principle discovered by Symon and developed and elaborated principally by the Midwestern University Research Association group (MURA). If successful, this development would make possible higher beam currents in several types of accelerators.

The FFAG principle is at present in process of theoretical and experimental investigation. No practical accelerator using it has yet been built, but model work is in progress. It is important that the development should proceed as early as possible to a large working model in order to place the whole FFAG development on a firmer foundation. The accelerators which will become feasible, should the FFAG development proceed as expected, are included in Table III. Each of the machines in this list would open up new regions by yielding hitherto unprecedented beam intensities (some of them producing radiations on the megawatt level).

If high intensity FFAG accelerators above 10 Bev can be built, there is the possibility of producing reactions which would require a single accelerator of quite impractical size to duplicate. This would be achieved by allowing intense beams from two equal energy machines to "collide" so that the center of mass of two interacting particles



CENTER OF MASS ENERGY AS A FUNCTION OF INCIDENT PARTICLE ENERGY FOR ELECTRONS ON FREE PROTONS AND PROTONS ON FREE PROTONS. NOTE THAT, FOR BOUND NUCLEONS THE EFFECTIVE THRESHOLDS ARE LOWERED BY SEVERAL PERCENT.

would be at rest and the sum of their kinetic energies would be available. (At intensities available in present machine types, the number of interactions would be too small to observe.) Thus, by means of high intensities in the individual accelerators, a center of mass energy equivalent to that of a very high energy single accelerator would be produced, though at very low effective intensities. It should be pointed out, however, that the two methods result in quite different situations from the standpoint of experiments. The energy distribution of the various resulting particles will be quite different in the laboratory system. Furthermore, there may be practical difficulties in making observations with the colliding beam technique; certainly the primary interaction cannot be directly observed. Thus this approach and the direct approach to "colossal" energies offer different sets of advantages and liabilities. Since increased energy is most important, it is justifiable to press on vigorously along both paths.

Electron and proton accelerators yield rather different kinds of fundamental information; both have proved valuable. Thus, higher energy accelerators for both electrons and protons are desirable. Because of the phenomenon of radiation loss peculiar to circular electron accelerators, the highest electron energies (above 7 - 10 Bev) are practically attainable only from linear accelerators.

The acceleration of particles heavier than protons has a certain interest, but mainly in other fields of science than particle physics. The FFAG accelerators, and some existing types, can be adapted to accelerate heavier particles, frequently without great difficulty.

It has long been realized that the sizes of present accelerators are defined by the maximum magnetic field attainable with practical devices or by the maximum electric fields which can be maintained in a vacuum. Frequent efforts have been made to push these parameters to higher magnitudes; all attempts fall essentially into the following three classes: (a) the use of pulsed magnetic fields to obtain transient high values of magnetic field; (b) the use of discharges to maintain a large magnetic field not limited by the properties of ordinary materials; (c) the use of "cooperative phenomena", namely the processes by which many electrons are made to combine their energies to transfer it, say, to one proton.

Many attempts on the first method have been made, but none of them has been notably successful. It is clear that machines based on pulsed magnetic fields may possibly result in reduced-size instruments, but will certainly not push the energy limits of such machines beyond their present boundaries.

Uses of gas discharges and cooperative phenomena have been proposed at various times. The first such proposal, to the best of our knowledge, is due to Thoneman in England; more detailed proposals have recently been made by Budker and Veksler at the 1956 CERN Symposium. It is common to all such proposals that the gap between theory and practical realization is large, since it appears to be exceedingly difficult to predict quantitatively all phenomena in gas discharges. Intensive experiments on these subjects are clearly indicated. However, it would be very unwise to base any planning on the success of such attempts. It is our opinion that unless such devices, in addition to producing a workable accelerator, also push the limits of current and voltage attainable with such machines beyond those presently attainable, the present size and cost of accelerator installations will not be materially affected.

The following table shows the existing and contemplated kinds of accelerators.

ON FREE PROTONS ARE LOWERED BY SEVERAL PERCENT.
THE EFFECTIVE THRESHOLDS

TABLE III .--CHARACTERISTICS OF HIGH ENERGY MACHINES

	Pulsed Field Weak Focusing Porton Synchrotron	Pulsed Field AG Porton Synchrotron	Proton Linear Accelerator	Pulsed Field Electron Synchrotron	Electron Linear Accelerator
Appropriate Energy Range	1 to 12 Bev	10 - very high	0 to very high	0 to 10 Bev	0 to very high
Particle Accelerated	Proton	Proton	Proton	Electron	Electron
Beam Currents (Average)	10^{-6} - 10^{-6} amp. 10^{11} - 10^{12} protons/pluse	10^{-6} - 10^{-8} amp.	10^{-6} - 10^{-5} amp. 10^{12} protons/pluse	10^{-7} amp. 10^{11} electrons per pulse	10^{-3}amp. 10^{12} electrons per pulse
Output Beam Duty Cycle	6×10^{-2} can be increased	10^{-2}	10^{-2}	10^{-2}	10^{-4} or less
Repetition rate	20 to 0.1 c.p.s.	0.1 - 1 c.p.s	30 c.p.s.	6 - 60 c.p.s.	60 to 360 c.p.s.
Energy Spectrum	Depends on beam programming. Can be 0.1 per cent.	May be 0.1 per cent	0.1 - 0.01 per cent above 1 Bev	Depends on beam programming. Can be 0.1 per cent	~ 2 per cent
Variability of Energy	Easy	Easy	Possible	Easy	Easy
Remarks	External proton beam easy. External neutron beam.	External beam difficult	External proton beam of high quality. External neutron beam. Cost relatively high.	Internal electron beam available at straight sections. External X-ray beam of good quality.	External electron and X-ray beams of good quality.
Status (U.S. and Abroad)	Operating 1,3,6 Bev Construction 10 Bev Design 12 Bev	Construction CERN: 25 Bev BNL: 25 - 30 Design Moscow: 50 Bev	Operating 68 Mev Study 1 Bev	Operating 1.2 Bev Design 7 Bev (AG)	Operating .65 Bev Construction 2 Bev Study 15-45 Bev

	FFAG CW to Cyclotron	FFAG Synchrocyclotron	FFAG Protonsynchrotron	Colliding Beam Accelerator
Appropriate Energy Range	Up to rest mass of particle	Up to 2 - 3 Bev	2 - 25 Bev	Two 10 - 20 Bev machines, equivalent in available energy to one of 10^{11} - 10^{12} volts
Particle Accelerated	Proton, deuterons, etc.	Protons, deuterons, etc.	Protons (or other heavy particles)	Protons
Beam Currents (Average)	10^{-4} - 10^{-3} amp.	10^{-5} - 10^{-4} amp.	10^{-5} amp.	(Equivalent single beam current is very low.)
Output Beam Duty Cycle	100 per cent	1-3 x 10^{-2}	Depends on beam programming .0001 to 90%	Variable
Repetition Rate	Not applicable	Up to 1000 c.p.s. injection	1 c.p.s. for 30 c.p.s. injection	Variable (low)
Energy Spectrum	Not known; 2 percent or better	Not known; 2 percent or better	May be 1 percent or better	1% each beam
Variability of Energy	Easy with internal target. Possible but difficult with external beam.	Easy with internal target. Possible but difficult with external beam.	Easy with internal target. Possible with external beam.	Possible.
Remarks	External beam should be possible.	External beam should be possible.	External beam should be possible.	Internal targets only.
Status (U.S. and Abroad	Study 0.9 Bev		Model Studies. Design Studies.	Study

SUPPLEMENT TO THE REPORT *of the* ADVISORY PANEL ON HIGH-ENERGY ACCELERATORS *to the* NATIONAL SCIENCE FOUNDATION

National Science Foundation
Washington 25, D.C.
August 7-8, 1958

NSF 58-29

September 11, 1958

Dr. Alan T. Waterman, Director
National Science Foundation
Washington 25, D. C.

Dear Dr. Waterman:

At your request, the Advisory Panel on High Energy Accelerators was recently reconstituted to bring up to date the studies and recommendations last reported on October 4, 1956. Because of the inability of a few members of the earlier panel to serve again at this time, the composition was somewhat different than in 1956. The present members are:

H. L. Anderson, The University of Chicago
H. R. Crane, University of Michigan
B. T. Feld, Massachusetts Institute of Technology
E. J. Lofgren, University of California Radiation Laboratory
L. I. Schiff, Stanford University
F. Seitz, University of Illinois
R. Serber, Columbia University
M. G. White, Princeton University
R. R. Wilson, Cornell University
L. J. Haworth, Brookhaven National Laboratory, Chairman.

A meeting was held at the National Science Foundation on August 7 and 8 with all members present. After resurveying and thoroughly discussing the present national and world-wide situation in this field, the Panel decided that its 1956 recommendations and discussions are still basically valid. Consequently, our report, which is attached, is in the form of a supplement to the 1956 report. Our general recommendations, which we believe constitute a logical basis for national policy, have been restated with appropriate modifications to bring them up to date. In a subsequent section, we have expressed some of our views concerning the implementation of those recommendations. Since developments in this field have led to ever-larger machines so that individual projects now represent significant expenditures in money and technical effort even on a national scale, we have included more specific recommendations and suggestions than heretofore.

We trust that the present report will prove useful. We shall be happy, of course, to assist in any further way that you may desire.

Respectfully submitted for the Panel:

Leland J. Haworth,
Chairman

Attachment

REPORT OF ADVISORY PANEL ON HIGH ENERGY ACCELERATORS

I. INTRODUCTION

The subject of ultra-high energy accelerators has been reviewed in the light of developments since the Panel Report of October 25, 1956. The Panel believes that, with appropriate modifications and additions to bring them up to date, its previous recommendations and suggested implementations continue to form a sound basis for national policy in this field. Accordingly, the present paper will be in the form of a supplement to that of 1956.

A number of developments during the intervening period have influenced our deliberations.

(1) The accumulation of experience in the multi-Bev range at the Bevatron, the Cosmotron and other accelerators has enriched our knowledge and increased the promise of the fruitfulness of the field.

(2) Extensions of the basic accelerator parameters have increased in scientific importance and in technical feasibility; the scientific need is matched by a body of qualified research personnel which, experience indicates, will continue to exceed the capacity of the presently authorized accelerators.

(3) Developments in the high energy field have proceeded rapidly abroad. In Western Europe, the CERN synchrocyclotron is in full-fledged operation; the Saclay proton synchrotron has been completed; the CERN proton synchrotron and the Orsay linear accelerator are nearing completion; and the Harwell 8 Bev proton synchrotron and numerous smaller machines are under design and construction.

The USSR has continued to demonstrate its determination to forge ahead in this field. In the 10 Bev proton synchrotron at Dubna, they have the highest energy accelerator yet completed. The 7 Bev strong focussing proton synchrotron in Moscow and the linear electron accelerator at Kharkov are nearing completion. A site has been chosen for a 50 Bev alternating gradient pulsed synchrotron.

(4) The authorization of the Argonne accelerator and the continued inflation have increased the future financial requirements for accelerators already committed to an estimated $60 to $80 million per year. Our estimate of this level has been increased somewhat by fuller realization of the constantly recurring requirements for substantial improvements and additions to existing installations.

(5) The cost of individual programs continues to grow with increased accelerator size and experimental complexity. Future installations will cost annually from $5 million for the smallest to as much as $25 million for the largest. Consequently, reasonable advances in the program in the next five years would bring the total rate to a level in excess of $100 million and probably to the neighborhood of $150 million per year.

Although no important new technical ideas have been brought forward, there has been substantial progress in the understanding of basic accelerator phenomena and in exploiting those phenomena. The important technical developments of the last two years include the following:

(1) Comprehensive and careful studies have adequately demonstrated the feasibility of extending to very high energies the linear method of accelerating electrons.

(2) Further study and successful electron model experiments at MURA have demonstrated the basic workability of two types of fixed field alternating gradient (FFAG) synchrotrons.

(3) The Ohkawa method of producing colliding beams within a single FFAG accelerator has been explored and an electron model is being constructed.

(4) The use of storage rings has increased in attractiveness and a promising colliding beam experiment of basic scientific as well as technical importance has been proposed, using 500 Mev electrons.

(5) Further exploration has reduced the hopes that useful accelerators can be developed through the use of cooperative phenomena such as plasma effects and the self-magnetic fields of circulating beams.

(6) Further experience, the prospect of higher energies, and the potentialities of colliding beams have increased the need for improved methods of beam analysis and particle detection.

(7) The multiplicity of data in hand and in prospect have led to increased need for and substantial development toward adequate data reduction and analysis methods.

II. GENERAL RECOMMENDATIONS

Recognizing the basic soundness of its previous recommendations and taking cognizance of more recent developments, the Panel recommends that:

1. The Government continue active support of high energy physics, including the design, construction and operation of, and experimentation with high energy accelerators.

2. The Department of Defense, the Atomic Energy Commission, and the National Science Foundation, which have important responsibilities for the promotion or utilization of science and technology, each engage directly in the support of high energy physics; in particular, that the Department of Defense and the National Science Foundation extend their support in this field to maintain important positions. (The Panel regretfully notes that the previously recommended extension of support by the DOD and the NSF has not yet been implemented.)

3. First priority be given to the financial support of the present program, which it is estimated will cost from $60 to $80 million per year by 1963.

4. National planning anticipate new facilities which will raise the total annual expenditure for high energy physics to upwards of $100 million and probably to the neighborhood of $150 million in the next five years. Though substantially higher than the estimates of two years ago, this rate is believed to be both necessary to maintain an adequate national program and feasible in terms of national resources.

5. The need for accelerators of a variety of characteristics continue to be recognized. The most important parameters are energy, intensity, and kind of particle. In situations where a choice is to be made, it is usually better to extend the range of these important parameters than to increase the number of functionally similar accelerators.

6. Adequate support be given to research and development pointed toward new types of accelerators.

7. No fixed general policy be made with regard to the location of new accelerators at individual universities, national laboratories or other research establishments; but that each proposal be reviewed on its merits with due regard to the research that will be done, the stimulation to science, and the opportunities for training.

III. IMPLEMENTATION OF GENERAL RECOMMENDATIONS

The Panel reaffirms its previous suggestions for implementing its recommendations and notes with gratification the many positive steps that have been taken. The following additional suggestions and discussion may be helpful.

Extension of Parameters

The first priority in expanding the accelerator program should be to extend the parameters of our machines to produce electrons and protons of very high energy and to produce high currents of electrons and protons. The scientific purposes to be served can be stated with some definiteness.

The prime problem of high energy physics continues to be the understanding of elementary particles and the basic natural laws.

One aspect of the problem is to learn the properties and systematics of the various particles. This purpose would be served by a moderate energy high current proton machine. It would produce for study "strange" particles in large numbers; it might also lead to the identification of new particles which, for reason of rarity or of unfavourable characteristics, are difficult to find.

There is another aspect of the problem which may be equally relevant to its solution. This concerns the structure of the particles. Something has already been learned of the structure of the nucleon, and one would expect that the pi meson and the multiplicity of other strange new particles also possess structures. The very high energy machines can be described as intended to explore such structures. This may be done by probing to very small distances (e.g., with high energy electrons) or by violent disruptions of the structures (e.g., with high energy protons or electrons).

A similar problem arises when one considers weakly interacting particles. High energy-electron scattering has a like purpose, and could constitute another step in the long development of our understanding of electromagnetic phenomena.

We have described the confidently anticipated purposes of the various types of new machines. The history of physics suggests that the unanticipated discoveries may be no less important.

In view of these goals and the state of the accelerator art, the following lines of development seem most important.

1. Ultra-High Energy Electron Accelerator: The AEC, NSF and DOD have before them a proposal from Stanford University for an electron linear accelerator of ultimate energy between 30 and 45 Bev which moreover produces very high currents. The Panel believes that the proposal is scientifically and technically sound and recommends that this accelerator be built as soon as possible.

2. Very High Intensity Proton Accelerator: Such an accelerator in the 3 to 10 Bev range would be a valuable addition to the complex of accelerators in the United States and appropriate techniques seem to be available. However, no actual proposal is sufficiently advanced to warrant commitment at the present time. Encouragement should be given to the development of suitable proposals for such a machine.[1]

3. Ultra-High Energy Proton Accelerator: The center of mass energy of the Brookhaven and CERN proton synchrotrons will be about 6 Bev. It would be possible to extrapolate their design principle to give another factor of, say, three in center of mass energy (about 200 Bev laboratory energy). Although expensive, it may eventually be worthwhile to build an accelerator of this type. The Panel recommends no action at this time, noting that there is no proposal before any of the Government agencies.

4. Clashing Beams: The attainment of high center of mass energies by the clashing beam technique seems to be an attractive possibility, and to represent the only possible scheme for making a very large step in center of mass energies. The Panel believes that this important idea should be actively pursued. However, the attractiveness must not obscure the very real technical difficulties of building such an accelerator and the equally great difficulties in devising experimental techniques appropriate to it. The difficulties have been noted in the "Summary of Outside Technical Review of the Second MURA Proposal".

   The Panel recommends that before such a large-scale undertaking as that proposed by MURA be embarked upon, certain steps should be taken at MURA and other interested laboratories. These include:

   (a) Full interpretation of the performance of electron models.

[1] It should be noted that the machine currently proposed by MURA could be used as a single beam accelerator of very high intensity at 15 Bev. However, the specific method was chosen for its applicability to clashing beams (see below) and is more complex and much larger and costlier than would be necessary for single beam purposes alone.

(b) Serious consideration of building a colliding beam proton machine of a few Bev.

(c) Extensive study of alternative methods such as storage rings and, if and when deemed feasible, by an installation at an appropriate proton accelerator. (An actual installation is not meant to be a necessary antecedent to a large clashing beam accelerator.)

(d) The Stanford-Princeton colliding electron beam experiment using storage rings and an existing linear accelerator.

(e) Simultaneous development of experimental methods and detecting devices for use with clashing beams.

5. New Acceleration Methods: It is very important that the search for new methods of guiding and accelerating particles should continue. However, it must be noted that no such developments are near realization at the present time.

Detection and Data Reduction Methods

Hand in hand with accelerator advances must go the development of new techniques for beam analysis, particle detection and data reduction. The development and construction of equipment for these purposes is both difficult and expensive, demanding ingenuity and effort comparable to the development of the accelerators themselves. It is essential to encourage and support major efforts aimed at the augmentation of existing techniques in these fields.

Efficient Utilization of Available Talents

Many of the important accelerator advances of recent years have come from the ideas and work of the MURA group. Continued progress in these developments (e.g., the FFAG and colliding beams) is strongly dependent on the continuation and intensification of the MURA program. Consequently the Panel urges that the MURA group be supported on a continuing basis with the funds and facilities necessary for its participating intensively in the development, construction and operation of accelerators.

In contrast to the major developments in accelerators proper, which are increasingly concentrated in a few places, the basic scientific ideas and discoveries continue to come preponderately from the scientists of many universities. For this reason, and in view of the great importance of training future scientists, it is important that University scientists have access to appropriate facilities. Unfortunately, although generous cooperation has been extended by each center, the capacity of their machines is limited. Consequently, while support of the present program and development of advanced accelerators should continue to have the first and second priorities respectively, it is to be hoped that there will be room also for a few additional conventional accelerators in the hands of single or small groups of universities. Such groups should take advantage of well established designs and the aid of the experienced groups to build machines with a minimum of effort and expense.

Respectfully Submitted,

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September 5, 1958

APPENDIX

Specific developments since the 1956 report are such as to warrant revising and bringing up to date the tables appended to that report. Such revisions are attached. Since the discussions of the 1956 appendices are still generally applicable, and since the major progress has been reported above, the textual material has not been rewritten even though obsolete in minor ways.

There is, however, one important development not discussed in the 1956 report, namely, the use of storage rings for producing colliding beams. This approach would utilize two intersecting d.c. ring magnets to store high energy particles which are injected into the rings from appropriate accelerators, i.e., synchrotrons or linear accelerators. When sufficient stored beam intensities have been reached, secondary interaction products from the constantly colliding storage beams can hopefully be observed.

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As in any colliding beam device, the effective intensities would, of course, be very low and the background problems great. The problems of arranging effective experiments would be similar to those for a colliding beam accelerator such as that proposed by MURA.

One definite proposal has been made for the use of storage rings using electrons from the Stanford 700 Mev Linear Accelerator.

TABLE I.--Accelerator types tabulated by energy, current, and type of particle. The intensity comparisons are more or less line by line and, in general, decrease with increasing energy, particularly in the magnetic machines. (See Table III.) Presently authorized U.S. accelerators are identified in terms of the institution where the work is carried out; tentative completion dates of machines under construction are given in brackets.

Energy (Bev)	PROTON		ELECTRON	
	'High' current	'Low' current	'High' current	'Low' current
~ 1	Linear accelerator or Cyclotron STUDY	Synchrocyclotron (Univ. California) OPERATING	Linear accelerator (Stanford) OPERATING	Synchrotron (Cornell) OPERATING (Calif.Inst.Tech.)"
~ 3	High-intensity synchrotron[1] (Princeton-Penn.) (1965)	Synchrotron (Brookhaven) OPERATING	.....	.....
~ 7	High pulse rate AGS - STUDY Fixed-field alternating-gradient synchrotron[2]	Synchrotron (Univ. California) OPERATING	.....	Alternating-gradient synchrotron (Harvard-MIT) (1965)
~ 15	Fixed-field alternating-gradient synchrotron[2]	Synchrotron (Argonne) (1962)	Linear accelerator[3]	.....
~ 30	.....	Alternating-gradient synchrotron (Brookhaven) (1965) Storage rings STUDY		.....
100-200	.....	Alternating-gradient synchrotron STUDY	.....	.....
≈ 500 BE[4]	.....	Colliding beam STUDY[2] (very low current)	.....	.....
1000 BE[4]		.....	.....	Colliding electron beams in storage rings STUDY (very low current)

([1])The Princeton (weak focus) synchrotron is expected to deliver an average current of approximately 5×10^{-7} amperes, which, although "high" compared to that of the Brookhaven Cosmotron ($\approx 10^{-8}$ amperes) is "low" compared to the potentialities of other machines in that column (See Table III). ([2])Model testing of basic principles now underway. ([3])Preliminary design completed. ([4])BE denotes energy equivalent obtained by means of colliding beam techniques.

TABLE II.--Multi-Bev Installations Under Construction, in Design, or Under Consideration

Machine	Particle	Energy	Location	Status	Expected Completion
Synchrotron	proton	1 Bev	Delft (Holland)	Construction	
Synchrotron	proton	3 Bev	Princeton-Pennsylvania (USA)	Construction	1960
Alternating-gradient synchrotron	proton	7 Bev	USSR	Construction	1959
Synchrotron	proton	6-8 Bev	AERE-Harwell (UK)	Construction	1961
Alternating-gradient synchrotron	proton	~10 Bev	Oak Ridge Nat'l Lab. (USA)	Proposal made	
Synchrotron (air core, low rep. rate)	proton	10 Bev	Canberra (Australia)	Construction	~1960
Alternating-gradient synchrotron	proton	10 Bev	University of Rochester (USA)	Study	
Synchrotron	proton	15 Bev	Argonne National Lab. (USA)	Construction	1962
Alternating-gradient synchrotron	proton	25 Bev	CERN (Switzerland)	Construction	1960
Alternating-gradient synchrotron	proton	25-30 Bev	Brookhaven National Lab. (USA)	Construction	1960
Storage Rings--synchrotron	proton	30 Bev	Princeton (USA)	Study	
Alternating-gradient synchrotron	proton	50 Bev	USSR	Study	
Two-way 15 Bev colliding beam fixed-field alternating-gradient synchrotron	proton	530 Bev Equivalent	MURA (USA)	Proposal made	
Synchrotron	electron	1 Bev	Stockholm (Sweden)	Construction	1959
Synchrotron	electron	1.5 Bev	Rome (Italy)	Construction	1959
Linear accelerator	electron	2 Bev	Paris (France)	Construction	1959
Linear accelerator	electron	2 Bev	Kharkov (USSR)	Construction	1959
Linear accelerator	electron	3 Bev	Amsterdam (Holland)	Study	
Synchrotron	electron	6-8 Bev	Hamburg (Germany)	Study	
Synchrotron	electron	7 Bev	Harvard-MIT, Cambridge (USA)	Construction	1960
Linear accelerator	electron	15-45 Bev	Stanford University (USA)	Proposal made	
Storage Rings--linear accelerator	electron	1000 Bev Equivalent	Stanford University (USA)	Proposal made	

TABLE III.--CHARACTERISTICS OF HIGH ENERGY MACHINES

	Pulsed Field Weak Focusing Proton Synchrotron	Pulsed Field AG Proton Synchrotron	Proton Linear Accelerator	Pulsed Field Electron Synchrotron	Electron Linear Accelerator
Appropriate Energy Range	1 to 12 Bev	10 - very high	0 to very high	0 to 10 Bev	0 to very high
Particle Accelerated	Proton	Proton	Proton	Electron	Electron
Beam Currents (Average)	10^{-8} - 10^{-6} amp. 10^{10} - 10^{12} protons/pulse	10^{-9} - 10^{-8} amp.	10^{-6} - 10^{-5} amp. 10^{12} protons/pulse	10^{-7} amp. 10^{11} electrons per pulse	10^{-5} amp. 10^{12} electrons per pulse
Output Beam Duty Cycle	6×10^{-2} can be increased	10^{-2}	10^{-2}	10^{-2}	10^{-4} or less
Repetition Rate	0.1 to 20 c.p.s.	0.1 - 1 c.p.s.	30 c.p.s.	6 - 60 c.p.s.	60 to 360 c.p.s.
Energy Spectrum	Depends on beam programming. Can be 0.1 per cent.	May be 0.1 per cent	0.1 - 0.1 per cent above 1 Bev	Depends on beam programming. Can be 0.1 per cent.	$\sim$2 per cent
Variability of Energy	Easy	Easy	Possible	Easy	Easy
Remarks	External proton beam easy. External neutron beam.	External beam may be difficult.	External proton beam of high quality. External neutron beam. Cost relatively high.	Internal electron beam available at straight sections. External X-ray beam of good quality.	External electron and X-ray beams of good quality.
Status (U.S. and Abroad)	Operating: 1,3,6,10 Bev Construction: 3 and 12 Bev	Construction: 7,25 - 30 Bev Design: 50 Bev	Operating: 68 Mev Study: 1 Bev	Operating: 1 - 1.2 Bev Construction: 7 Bev (AG)	Operating: 0.70 Bev Construction: 2 Bev Proposed: 15-45 Bev

TABLE III.--CHARACTERISTICS OF HIGH ENERGY MACHINES--Continued

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	FFAG CW Proton Cyclotron	FFAG Synchrocyclotron	FFAG Protonsynchrotron	Colliding Beam Proton Accelerator	Storage Rings (Electrons or Protons)
Appropriate Energy Range	Up to rest mass of particles	Up to 2 - 3 Bev	2 - 25 Bev	Equivalent Energies of 0 - very high	0 - very high
Particle Accelerated	Proton, deuterons, etc.	Protons, deuterons, etc.	Protons (or other heavy particles)	Protons	Requires separate accelerator injector - protons, deuterons, electrons, etc.
Beam Currents (Average)	10^{-4} - 10^{-3} amp.	10^{-5} - 10^{-4} amp.	10^{-5} amp.	(Equivalent single beam current is very low.)	(Equivalent single beam current is very low
Output Beam Duty Cycle	100 per cent	1-3 x 10^{-2}	Depends on beam programming 10^{-4} 90%	Variable	100 per cent
Repetition Rate	Not applicable	Up to 1000 c.p.s.	1 c.p.s. for 30 c.p.s. injection	Variable (low)	Not pulsed
Energy Spectrum	Not known; 2 per cent or better	Not known; 2 per cent or better	May be 1 per cent or better	1% each beam	May be 0.1 per cent
Variability of Energy	Easy with internal target. Possible but difficult with external beam.	Easy with internal target. Possible but difficult with external beam.	Easy with internal target. Possible with external beam.	Possible	Depends upon variability of injector energy
Remarks	External beam should be possible.	External Beam should be possible.	External beam should be possible.	Internal targets only.	Can only study interactions between identical particles
Status (U.S. and Abroad)	Proposed: 0.9 Bev		Model Studies. Design Studies.	Proposed: Single device with opposite circulating 15 Bev beams. At collision equivalent single beam accelerator energy is 540 Bev.	Study: Equivalent Energy 30 Bev protons Proposed: Equivalent Energy 1000 Bev. electrons

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REFER

September 11, 1958

Dr. Alan T. Waterman, Director
National Science Foundation
Washington 25, D. C.

Dear Dr. Waterman:

At your request, the Advisory Panel on High Energy Accelerators was recently reconstituted to bring up to date the studies and recommendations last reported on October 4, 1956. Because of the inability of a few members of the earlier panel to serve again at this time, the composition was somewhat different than in 1956. The present members are:

H. L. Anderson, The University of Chicago
H. R. Crane, University of Michigan
B. T. Feld, Massachusetts Institute of Technology
E. J. Lofgren, University of California Radiation Laboratory
L. I. Schiff, Stanford University
F. Seitz, University of Illinois
R. Serber, Columbia University
M. G. White, Princeton University
R. R. Wilson, Cornell University
L. J. Haworth, Brookhaven National Laboratory, Chairman.

A meeting was held at the National Science Foundation on August 7 and 8 with all members present. After resurveying and thoroughly discussing the present national and world-wide situation in this field, the Panel decided that its 1956 recommendations and discussions are still basically valid. Consequently, our report, which is attached, is in the form of a supplement to the 1956 report. Our general recommendations, which we believe constitute a logical basis for national policy, have been restated with appropriate modifications to bring them up to date. In a subsequent section, we have expressed some of our views concerning the implementation of those recommendations. Since developments in this field have led to ever-larger machines so that individual projects now represent significant expenditures in money and technical effort even on a national scale, we have included more specific recommendations and suggestions than heretofore.

We trust that the present report will prove useful. We shall be happy, of course, to assist in any further way that you may desire.

Respectfully submitted for the Panel:

Leland J. Haworth,
Chairman

Attachment

REPORT OF ADVISORY PANEL ON HIGH ENERGY ACCELERATORS

I - INTRODUCTION

The subject of ultra-high energy accelerators has been reviewed in the light of developments since the Panel Report of October 25, 1956. The Panel believes that, with appropriate modifications and additions to bring them up to date, its previous recommendations and suggested implementations continue to form a sound basis for national policy in this field. Accordingly, the present paper will be in the form of a supplement to that of 1956.

A number of developments during the intervening period have influenced our deliberations.

(1) The accumulation of experience in the multi-Bev range at the Bevatron, the Cosmotron and other accelerators has enriched our knowledge and increased the promise of the fruitfulness of the field.

(2) Extensions of the basic accelerator parameters have increased in scientific importance and in technical feasibility; the scientific need is matched by a body of qualified research personnel which, experience indicates, will continue to exceed the capacity of the presently authorized accelerators.

(3) Developments in the high energy field have proceeded rapidly abroad. In Western Europe, the CERN synchrocyclotron is in full-fledged operation; the Saclay proton synchrotron has been completed; the CERN proton synchrotron and the Orsay linear accelerator are nearing completion; and the Harwell 8 Bev proton synchrotron and numerous smaller machines are under design and construction.

The USSR has continued to demonstrate its determination to forge ahead in this field. In the 10 Bev proton synchrotron at Dubna, they have the highest energy accelerator yet completed. The 7 Bev strong focussing proton synchrotron in Moscow and the linear electron accelerator at Kharkov are nearing completion. A site has been chosen for a 50 Bev alternating gradient pulsed synchrotron.

(4) The authorization of the Argonne accelerator and the continued inflation have increased the future financial requirements for accelerators already committed to an estimated $60 to $80 million per year. Our estimate of this level has been increased somewhat by fuller realization of the constantly recurring requirements for substantial improvements and additions to existing installations.

(5) The cost of individual programs continues to grow with increased accelerator size and experimental complexity. Future installations

will cost annually from $5 million for the smallest to as much as $25 million for the largest. Consequently, reasonable advances in the program in the next five years would bring the total rate to a level in excess of $100 million and probably to the neighborhood of $150 million per year.

Although no important new technical ideas have been brought forward, there has been substantial progress in the understanding of basic accelerator phenomena and in exploiting those phenomena. The important technical developments of the last two years include the following:

(1) Comprehensive and careful studies have adequately demonstrated the feasibility of extending to very high energies the linear method of accelerating electrons.

(2) Further study and successful electron model experiments at MURA have demonstrated the basic workability of two types of fixed field alternating gradient (FFAG) synchrotrons.

(3) The Ohkawa method of producing colliding beams within a single FFAG accelerator has been explored and an electron model is being constructed.

(4) The use of storage rings has increased in attractiveness and a promising colliding beam experiment of basic scientific as well as technical importance has been proposed, using 500 Mev electrons.

(5) Further exploration has reduced the hopes that useful accelerators can be developed through the use of cooperative phenomena such as plasma effects and the self-magnetic fields of circulating beams.

(6) Further experience, the prospect of higher energies, and the potentialities of colliding beams have increased the need for improved methods of beam analysis and particle detection.

(7) The multiplicity of data in hand and in prospect have led to increased need for and substantial development toward adequate data reduction and analysis methods.

II - GENERAL RECOMMENDATIONS

Recognizing the basic soundness of its previous recommendations and taking cognizance of more recent developments, the Panel recommends that:

1. The Government continue active support of high energy physics, including the design, construction and operation of, and experimentation with high energy accelerators.

2. The Department of Defense, the Atomic Energy Commission, and the National Science Foundation, which have important responsibilities for the promotion or utilization of science and technology, each engage directly in the support of high energy physics; in particular, that the Department of Defense and the National Science Foundation extend their support in this field to maintain important positions. (The Panel regretfully notes that the previously recommended extension of support by the DOD and the NSF has not yet been implemented.)

3. First priority be given to the financial support of the present program, which it is estimated will cost from $60 to $80 million per year by 1963.

4. National planning anticipate new facilities which will raise the total annual expenditure for high energy physics to upwards of $100 million and probably to the neighborhood of $150 million in the next five years. Though substantially higher than the estimates of two years ago, this rate is believed to be both necessary to maintain an adequate national program and feasible in terms of national resources.

5. The need for accelerators of a variety of characteristics continue to be recognized. The most important parameters are energy, intensity, and kind of particle. In situations where a choice is to be made, it is usually better to extend the range of these important parameters than to increase the number of functionally similar accelerators.

6. Adequate support be given to research and development pointed toward new types of accelerators.

7. No fixed general policy be made with regard to the location of new accelerators at individual universities, national laboratories or other research establishments; but that each proposal be reviewed on its merits with due regard to the research that will be done, the stimulation to science, and the opportunities for training.

III – IMPLEMENTATION OF GENERAL RECOMMENDATIONS

The Panel reaffirms its previous suggestions for implementing its recommendations and notes with gratification the many positive steps that have been taken. The following additional suggestions and discussion may be helpful.

Extension of Parameters

The first priority in expanding the accelerator program should be to extend the parameters of our machines to produce electrons and protons of very high energy and to produce high currents of electrons and protons. The scientific purposes to be served can be stated with some definiteness.

The prime problem of high energy physics continues to be the understanding of elementary particles and the basic natural laws.

One aspect of the problem is to learn the properties and systematics of the various particles. This purpose would be served by a moderate energy high current proton machine. It would produce for study "strange" particles in large numbers; it might also lead to the identification of new particles which, for reason of rarity or of unfavourable characteristics, are difficult to find.

There is another aspect of the problem which may be equally relevant to its solution. This concerns the structure of the particles. Something has already been learned of the structure of the nucleon, and one would expect that the pi meson and the multiplicity of other strange new particles also possess structures. The very high energy machines can be described as intended to explore such structures. This may be done by probing to very small distances (e.g., with high energy electrons) or by violent disruptions of the structures (e.g., with high energy protons or electrons).

A similar problem arises when one considers weakly interacting particles. High energy-electron scattering has a like purpose, and could constitute another step in the long development of our understanding of electromagnetic phenomena.

We have described the confidently anticipated purposes of the various types of new machines. The history of physics suggests that the unanticipated discoveries may be no less important.

In view of these goals and the state of the accelerator art, the following lines of development seem most important.

1. Ultra-High Energy Electron Accelerator: The AEC, NSF and DOD have before them a proposal from Stanford University for an electron linear accelerator of ultimate energy between 30 and 45 Bev which moreover produces very high currents. The Panel believes that the proposal is scientifically and technically sound and recommends that this accelerator be built as soon as possible.

2. Very High Intensity Proton Accelerator: Such an accelerator in the 3 to 10 Bev range would be a valuable addition to the complex of accelerators in the United States and appropriate techniques seem to be available. However, no actual proposal is sufficiently advanced to warrant commitment at the present time. Encouragement should be given to the development of suitable proposals for such a machine.(1)

3. Ultra-High Energy Proton Accelerator: The center of mass energy of the Brookhaven and CERN proton synchrotrons will be about 6 Bev. It would be possible to extrapolate their design principle to give another factor of, say, three in center of mass energy (about 200 Bev

(1) It should be noted that the machine currently proposed by MURA could be used as a single beam accelerator of very high intensity at 15 Bev. However, the specific method was chosen for its applicability to clashing beams (see below) and is more complex and much larger and costlier than would be necessary for single beam purposes alone.

laboratory energy). Although expensive, it may eventually be worthwhile to build an accelerator of this type. The Panel recommends no action at this time, noting that there is no proposal before any of the Government agencies.

4. Clashing Beams: The attainment of high center of mass energies by the clashing beam technique seems to be an attractive possibility, and to represent the only possible scheme for making a very large step in center of mass energies. The Panel believes that this important idea should be actively pursued. However, the attractiveness must not obscure the very real technical difficulties of building such an accelerator and the equally great difficulties in devising experimental techniques appropriate to it. The difficulties have been noted in the "Summary of Outside Technical Review of the Second MURA Proposal".

   The Panel recommends that before such a large-scale undertaking as that proposed by MURA be embarked upon, certain steps should be taken at MURA and other interested laboratories. These include:

   (a) Full interpretation of the performance of electron models.

   (b) Serious consideration of building a colliding beam proton machine of a few Bev.

   (c) Extensive study of alternative methods such as storage rings and, if and when deemed feasible, by an installation at an appropriate proton accelerator. (An actual installation is not meant to be a necessary antecedent to a large clashing beam accelerator.)

   (d) The Stanford-Princeton colliding electron beam experiment using storage rings and an existing linear accelerator.

   (e) Simultaneous development of experimental methods and detecting devices for use with clashing beams.

5. New Acceleration Methods: It is very inportant that the search for new methods of guiding and accelerating particles should continue. However, it must be noted that no such developments are near realization at the present time.

Detection and Data Reduction Methods

Hand in hand with accelerator advances must go the development of new techniques for beam analysis, particle detection and data reduction. The development and construction of equipment for these purposes is both difficult and expensive, demanding ingenuity and effort comparable to the development of the accelerators themselves. It is essential to encourage and support major efforts aimed at the augmentation of existing techniques in these fields.

Efficient Utilization of Available Talents

Many of the important accelerator advances of recent years have come from the ideas and work of the MURA group. Continued progress in these developments (e.g., the FFAG and colliding beams) is strongly dependent on the continuation and intensification of the MURA program. Consequently the Panel urges that the MURA group be supported on a continuing basis with the funds and facilities necessary for its participating intensively in the development, construction and operation of accelerators.

In contrast to the major developments in accelerators proper, which are increasingly concentrated in a few places, the basic scientific ideas and discoveries continue to come preponderately from the scientists of many universities. For this reason, and in view of the great importance of training future scientists, it is important that University scientists have access to appropriate facilities. Unfortunately, although generous cooperation has been extended by each center, the capacity of their machines is limited. Consequently, while support of the present program and development of advanced accelerators should continue to have the first and second priorities respectively, it is to be hoped that there will be room also for a few additional conventional accelerators in the hands of single or small groups of universities. Such groups should take advantage of well established designs and the aid of the experienced groups to build machines with a minimum of effort and expense.

Respectfully Submitted,

H. L. Anderson, The University of Chicago

H. R. Crane, University of Michigan

B. T. Feld, Massachusetts Institute of Technology

E. J. Lofgren, University of California Radiation Laboratory

L. I. Schiff, Stanford University

F. Seitz, University of Illinois

R. Serber, Columbia University

M. G. White, Princeton University

R. R. Wilson, Cornell University

I. J. Haworth, Brookhaven National Laboratory, Chairman

September 5, 1958

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Linear accelerator	electron	2 Bev	Paris (France)	Construction	1959
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Beam Currents (Average)	10^{-8} - 10^{-6} amp. 10^{10} - 10^{12} protons/pulse	10^{-9} - 10^{-8} amp.	10^{-6} - 10^{-5} amp. 10^{12} protons/pulse	10 10
Output Beam Duty Cycle	6×10^{-2} can be increased	10^{-2}	10^{-2}	10
Repetition Rate	0.1 to 20 c.p.s.	0.1 - 1 c.p.s.	30 c.p.s.	6
Energy Spectrum	Depends on beam programming. Can be 0.1 per cent.	May be 0.1 per cent	0.1 - 0.01 per cent above 1 Bev	De pr be
Variability of Energy	Easy	Easy	Possible	Ba
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TERISTICS OF HIGH ENERGY MACHINES

on	Proton Linear Accelerator	Pulsed Field Electron Synchrotron	Electron Linear Accelerator
	0 to very high	0 to 10 Bev	0 to very high
	Proton	Electron	Electron
	10^{-6} - 10^{-5} amp. 10^{12} protons/pulse	10^{-7} amp. 10^{11} electrons per pulse	10^{-5} amp. 10^{12} electrons per pulse
	10^{-2}	10^{-2}	10^{-4} or less
	30 c.p.s.	6 - 60 c.p.s.	60 to 360 c.p.s.
	0.1 - 0.01 per cent above 1 Bev	Depends on beam programming. Can be 0.1 per cent.	~ 2 per cent
	Possible	Easy	Easy
	External proton beam of high quality. External neutron beam. Cost relatively high.	Internal electron beam available at straight sections. External X-ray beam of good quality.	External electron and X-ray beams of good quality.
	Operating: 68 Mev Study: 1 Bev	Operating: 1 - 1.2 Bev Construction: 7 Bev (AG)	Operating: 0.70 Bev Construction: 2 Bev Proposed: 15-45 Bev

FFAG CW Proton Cyclotron	FFAG Synchrocyclotron	FFAG Protonsynchrot
Up to rest mass of particle	Up to 2 - 3 Bev	2 - 25 Bev
Proton, deuterons, etc.	Protons, deuterons, etc.	Protons (or ot particles)
10^{-4} - 10^{-3} amp.	10^{-5} - 10^{-4} amp.	10^{-5} amp.
100 per cent	1-3 x 10^{-2}	Depends on bea 10^{-4} to 90%
Not applicable	Up to 1000 c.p.s.	1 c.p.s. for 3 injection
Not known; 2 per cent or better	Not known; 2 per cent or better	May be 1 per c
Easy with internal target. Possible but difficult with external beam.	Easy with internal target. Possible but difficult with external beam.	Easy with inte Possible with
External beam should be possible.	External beam should be possible.	External beam be possible.
Proposed: 0.9 Bev		Model Studies. Design Studies

	Colliding Beam Proton Acceler
nchrotron	
ev	Equivalent Energies of 0 - ve high
(or other heavy s)	Protons
•	(Equivalent single beam current is very low.)
on beam programming 90%	Variable
for 30 c.p.s. n	Variable (low)
per cent or better	1% each beam
h internal target. with external beam.	Possible
beam should ble.	Internal targets only.
udies. tudies.	Proposed: Single device with opposite circulating 15 Bev beams. At collision equivalen single beam accelerator ener is 540 Bev.

Accelerator	Storage Rings (Electrons or Protons)
0 - very	0 - very high
	Requires separate accelerator injector - protons, deuterons, electrons, etc.
m	(Equivalent single beam current is very low.)
	100 per cent
	Not pulsed
	May be 0.1 per cent
	Depends upon variability of injector energy
	Can only study interactions between identical particles
ce with 15 Bev uivalent or energy	Study: Equivalent Energy 30 Bev protons Proposed: Equivalent Energy 1000 Bev electrons

Jun

CORRELATION GUIDE

on

TWO-MILE LINEAR ACCELERATOR

Stanford University

Prepared by:

Division of Research
Atomic Energy Commission
Washington 25, D. C.

June 30, 1959

CORRELATION GUIDE FOR THE STANFORD ACCELERATOR PROPOSAL (1957), THE BROBECK REVIEW (1958), AND THE CONSTRUCTION PROJECT DATA SHEETS (1959).

I. INTRODUCTION

There are three major documents available at present which give detailed information about the Stanford University proposal to construct and operate a two-mile linear electron accelerator. These are:

(1) Stanford Proposal for a Two-Mile Linear Electron Accelerator (April 1957) submitted by Stanford University.

(2) Brobeck Review of the Stanford Proposal (June 1958) prepared by William M. Brobeck & Associates at the request of the AEC.

(3) Construction Project Data Sheets for the Linear Electron Accelerator (May 1959) compiled by Stanford University and the Divisions of Research, Finance, and Construction and Supply of the AEC.

The interval between the writing of each document is approximately one year and to some extent each of the latter two documents updates the previous one. It is the purpose of the present Correlation Guide to describe the Stanford project as submitted to Congress in greater detail by referring to the relevant parts of (1) and (2) to further amplify the data presented in (3).

In general, one may say that the original Stanford Proposal (1) provides the best description of the scientific objective and general philosophy of the project; the physical characteristics of the accelerator, tunnels, and buildings; and the beam extraction and experimental areas.

The Brobeck Review (2) is primarily an independent cost estimate which supercedes the cost estimate given in (1). The various appendices and drawings often furnish greater detail about items such as the cross section of the tunnels, the waveguide coupling arrangement, the RF system and control circuits, etc.

The Project Data Sheets (3) present, in essentially outline form, the proposed accelerator project as submitted to Congress. It may be more

fully understood by reference to the appropriate sections of (1) and (2), as indicated below.

The following major changes have been made in the project since (1) and (2) were written.

(a) The number of klystrons to be used is reduced to 240 from 480. Thus the energy range is reduced to 10-15 Bev from 15-25 Bev.

(b) It will no longer be necessary for Stanford to build a Klystron Factory, since commercial facilities will be available to fabricate these tubes.

(c) To the buildings at the End Station have been added a cafeteria, auditorium, fire station and two guard houses.

II. GUIDE TO THE STANFORD ACCELERATOR PROPOSAL

Sections I, II, III and IV of the Stanford Proposal - These first four sections require only minor corrections mostly occasioned by the change in Stage I to 240 klystrons and the shift in the energy range to 10-15 Bev. They still provide an excellent summary of the scientific objectives of the project and the physical characteristics of the accelerator and appurtenances. Tables IV-1, IV-2 and IV-3 which list the major specifications of the accelerator, klystrons, and tunnels are to be replaced by the revised tabulation in the Project Data Sheets, Section 8. The other necessary revisions to Sections I-IV are listed in detail in Appendix A of this Guide.

Section V of the Stanford Proposal - This section on Construction Costs is superceded by Section 10 of the Project Data Sheets which provides the present cost estimate.

Section VI of the Stanford Proposal - This section on Annual Research Operating Costs is to be compared with both Section IV and Appendix VII of the Brobeck Report. It is very difficult to predict exactly

the operating costs six years in advance for a machine which will be a unique facility. Thus the $15,000,000 quoted in the Project Data Sheets, Section 9 (d), must be regarded as an approximate figure. Escalation has not been included in the estimates given in Section VI and Appendix VII.

Appendices II-A, II-B, II-C and IV-A of the Stanford Proposal - These technical appendices on choice of wavelength, beam dynamics, shielding, and control and instrumentation are still pertinent, although further study could modify the conclusions somewhat. More detail on the latter is available in the Brobeck Analysis.

Appendix IV-B of the Stanford Proposal - The introduction to this appendix contains a useful description of the klystron requirements except that the number required for Stage I is now 240 and the pulse length is increased to 2.5 microseconds. The other parts require updating because a klystron factory is no longer necessary for reasons given above. Tables IV-B-1 and IV-B-2 on the klystron amplifiers are replaced by the table in Appendix B of this Guide.

Appendix IV-C of the Stanford Proposal - This description of the site and buildings is still up-to-date except for the addition of the cafeteria, auditorium, fire station and guard houses. Table IV-C-1, however, has been replaced by the Buildings and Structures part of Section 8 of the Project Data Sheets.

Appendix IV-D of the Stanford Proposal - The power requirements have been revised as follows:

Accelerator	31,600	kilowatts
Beam Switchyard	3,600	"
Target House	8,800	"
Administration, Shops & Labs	5,700	"
Pumps, Compressors & Refrigeration	9,000	"
Outdoors, etc.	500	"
	57,200	kilowatts

This is the breakdown for the power requirement of 60 megawatts given in the Project Data Sheets, Section 8.

III. GUIDE TO THE BROBECK REVIEW

Sections I, II and III of the Brobeck Review - These sections give the summary and breakdown of the construction cost estimates by Brobeck. The numerical values have been replaced by Section 10 of the Project Data Sheets. However, these follow a format similar to that used by Brobeck.

Section IV of the Brobeck Review - See remarks in this Guide under Section VI of the Stanford Proposal.

Appendix I of the Brobeck Review - In this appendix a description of the accelerator components such as the accelerating tube, klystron modulator, drive and control system, vacuum system, and injector is provided, which furnishes more detail in many respects than the Stanford Proposal. The machine will not necessarily be built and operated in just this manner, but a possible mode of operation is described. Drawings D-1 through D-12 illustrate some of these main components.

Appendix II of the Brobeck Review - Brobeck utilized Kaiser Engineers to prepare a cost estimate on the tunnels, end station, and buildings. Appendix II and Drawings 101-C through 103-E (11 in all) provide more detail about the above items than is given in the Stanford Proposal. Part D on the buildings in the end station area is amended by Section 8 of the Project Data Sheets.

Appendix III of the Brobeck Review - The prototype facility for accelerator improvement and klystron life testing is adequately described here.

Appendix IV of the Brobeck Review - This section provides a thorough analysis of the klystron lifetime and replacement problem, although some parts must be updated since the klystron factory is no longer required.

Appendix V of the Brobeck Review - At present the electroforming process for manufacturing the accelerating tube as described in this section is still the most satisfactory one, although alternative techniques are being investigated by Stanford and others.

Appendix VI of the Brobeck Review - This equipment analysis stands as written except for the replacement of the klystron factory by the klystron laboratory. See Project Data Sheets, Section 10, Item C-6.

Appendix VII of the Brobeck Review - See remarks in this Guide under Section VI of the Stanford Proposal.

Appendix VIII of the Brobeck Review - This appendix is current.

Appendix IX of the Brobeck Review - Stanford University has stated that it will give the government a long term lease to the site of the two-mile linear electron accelerator and end station for a $1 fee. The overhead rate to be paid Stanford during construction and operation has not yet been negotiated between Stanford and the AEC.

IV. GUIDE TO THE PROJECT DATA SHEETS

Sections 1 - 6 of the Project Data Sheets - These sections are self-explanatory.

Section 7 of the Project Data Sheets - See Figure I-1 of the Stanford Proposal and Appendix A of this Guide.

Section 8 of the Project Data Sheets - Amplification of the brief physical description will be found in:

Stanford Proposal - Sections I, II, III and IV
Appendix II-A, II-B, II-C, IV-A, IV-B, IV-C and IV-D

with the qualifications contained in Part II of this Guide.

Brobeck Review - Appendix I, II, III, IV, V and VIII

with the qualifications contained in Part III of this Guide.

Correlation Guide - Appendix A and B

Section 9 of the Project Data Sheets - Backup material for the justification of need will be found in:

Stanford Proposal - Sections I, II and III

The corrections necessary to the above sections will only slightly affect the statement pertaining to justification of need.

Sections 10 and 10a of the Project Data Sheets - These sections are the current cost estimates.

Section 11 of the Project Data Sheets - This section is self-explanatory.

APPENDIX A

(These corrections have been made in the following document)

Detailed Corrections to Section I - IV of the Stanford Proposal

Page 1, line 3	Delete 15,	insert 10	
Page 2, " 7	" several,	" about 30	
" 3, " 12	" $78,	" $105	
" 5, Fig. I-1	" line on klystron factory,		
" 6, line 17	" comma after Mev,	" period after Mev	
" 6, " 17 & 18	" remainder of sentence from "although at..."		
" 7, last line	" 15-Bev,	" 10-Bev	
" 16, Fig. II-1	" entire figure,	" Fig. A-1 of this Appendix	
" 19, line 6 from bottom	" μ-meson,	" π-meson	
" 22, Fig. II-3	" entire figure,	" Fig. A-2 of this Appendix	
" 27, line 4	" $20	" $50	
" 31, " 4	" 480	" 240	
" 31, " 5	" 15 - 30	" 10 - 20	
" 33, " 8	" 480	" 240	
" 33, " 10	" 2	" 2.5	
" 33, " 11	" 15,	" 10	
" 33, " 18	" 30,	" 20	
" 33, last 5 lines	" entire 5 lines		
" 34, first 8 "	" " 8 "		
" 35, Table IV-1)			
" 35, " IV-2)	Replace by table in Section 8 of Project Data Sheets		
" 35, " IV-3)			

APPENDIX B

PROJECT "M" KLYSTRON

TENTATIVE SPECIFICATIONS FOR GENERAL PLANNING ONLY

Description:

Pulsed amplifier klystron tube, 24 megawatt, 5 cavities, perveance k = 2 x 10^{-6} $A/V^{3/2}$, S-band, single frequency, magnetically focused, double waveguide output, coax input, liquid cooled, sealed-off.

			Absolute Ratings			Typical Operating Conditions					
						Operation A			Operation B		
		Units	Max.	Min.	Notes	Max.	Min.	Notes	Max.	Min.	Notes
Filament Voltage	E_f	volts	20	15	4						
Filament Current	I_f	amps	20	15							
Peak Forward Beam Voltage	e_{py}	kv	270	-	1	195	-	1	248	-	1
Peak Inverse Beam Voltage	e_{px}	kv	60	-	-	40	-	-	50	-	-
Peak Beam Current	i_k	amps	294	265	2	180	163	2	258	234	2
Peak Input Beam Power	P_i	Mw	79	71	-	35	32	-	64	58	-
Pulse Length Beam Voltage	τ_0	μsec	3	-	3	3	-	-	3	-	-
Pulse Repetition Frequency	prf	pps	180	-	-	360	-	-	180	-	-
Average Input Beam Power	P_i	kw	42.5	38.3	-	38	34.5	-	34.5	31.3	-
Frequency	f	Mc	2856	2856	-	2856	2856	-	2856	2856	-
Peak Drive Power	P_{drive}	watts	300	-	-	120	-	-	250	-	-
Peak Output rf Power	P_{out}	Mw	-	30	-	-	12	-	-	24	-
Pulse Length rf Output	τ_{rf}	μsec	-	2.5	-	-	2.5	-	-	2.5	-
Average Output rf Power	P_{out}	kw	-	13.5	-	-	10.8	-	-	10.8	-
Efficiency	η	%	-	38	-	-	35	-	-	38	-
Gain		db	-	50	-	-	50	-	-	50	-
Load		VSWR	1.5:1	-	-	1.5:1	-	-	1.5:1	-	-
Window Pressure		mmH_g	10^{-7}	-	-	10^{-7}	-	-	10^{-7}	-	-
Life		hours				-	2000	-	-	200	-

Cooling:	Water flow tbs at tbs psig Water temp. inlet tbs (to be specified)
Drift:	P_{out} to change not more than tbs percent per °F in inlet water temp.
Base:	Special plug-in socket - (see drawing No. ML....)
Input:	Female coaxial connector, type C - (mates with UG-573/U male connector)
Output:	2 Waveguides RG-48/U, connecting through special flange - (see drawing No. ML....)
Cooling Connections:	Two quick-disconnect type tbs.
Phase Modulation:	Phase modulation produced by stray heater magnetic field to be less than tbs°; produced by beam voltage changes to be less than tbs° per percent.
Focusing:	Permanent magnet focusing to be considered.
Radiation:	Shielding may be provided on collector.

Note 1 - Any short transient spike on the voltage pulse shall not exceed 10 percent in magnitude and 0.25 μs in duration.

Note 2 - The limits of acceptable current at operating voltage correspond to variation of $\pm$ 5 percent in perveance.

Note 3 - Pulse length measured at 70 percent of maximum voltage; minimum of 2.5 μsec flat top is required.

Note 4 - Heater power is expected to be 300 watts.

February 17, 1959

PROPOSAL FOR A TWO-MILE LINEAR ELECTRON ACCELERATOR

APRIL, 1957

This document serves to provide background information on the original proposal made by Stanford University to the AEC, the DOD and the NSF. The current plans differ from those proposed in 1957, principally by reduction of the number of klystron amplifiers used to power the accelerator.

STANFORD UNIVERSITY
STANFORD, CALIFORNIA

PREFACE AND ACKNOWLEDGEMENT

The basic plan for the two-mile accelerator is presented in the first six sections (I through VI) of this proposal. Supplementary information, covering some of the aspects of the proposal in more detail, is given in a series of Appendices (II-A, B, C and IV-A, B, C, D).

The possibility of constructing a two-mile, multi-Bev linear electron accelerator was first considered at Stanford in the early part of 1955. Members of the first group, which included F. Bloch, E. L. Ginzton, R. Hofstadter, W. K. H. Panofsky and L. I. Schiff, met several times during the course of the following year to discuss the scientific justification for such a machine and the general problems that would be involved in its construction. In April, 1956, a larger group met, composed primarily of members of the W. W. Hansen Laboratories of Physics, and it was decided to undertake the more detailed studies which led to this proposal. The proposal is the result of the part-time efforts of approximately 25 people working over a period of a year at Stanford, and of the contributions of several other organizations. Some of the members of the Stanford study group are listed below, with the chairmen of the several committees indicated in parentheses.

W. C. Barber	(Power Facilities)
K. L. Brown	(Specifications)
F. W. Bunker	
M. Chodorow	
E. L. Chu	
R. J. Debs	(Control and Instrumentation)
K. G. Dedrick	
L. H. Franklin	
E. L. Ginzton	
R. Hofstadter	
C. B. Jones	
J. H. Jasberg	(Klystron Specifications)
K. B. Mallory	
J. A. McIntyre	(Beam Switchyard and End Station)
R. F. Mozley	
R. B. Neal	(Accelerator Construction)

C. W. Olson
W. K. H. Panofsky (Radiation and Shielding)
F. V. L. Pindar (Site and Buildings)
L. I. Schiff (Administration)
H. W. Soderstrom (Klystron Factory)
S. Sonkin

In addition, several special studies were carried out on beam dynamics, accelerator structures, etc. The study as a whole has been under the direction of E. L. Ginzton and W. K. H. Panofsky.

We wish to acknowledge the valuable assistance of the following groups.

Utah Construction Company and Bechtel Corporation made extensive, independent studies of the site and tunnel problems, and submitted complete reports on their respective solutions. The site, tunnels, and target area discussed in this proposal are a synthesis of the solutions proposed by these two companies. All cost and specification information in this report stems directly from these studies.

Varian Associates assisted with the planning and cost estimates for the construction and operation of the klystron factory.

The University of California Radiation Laboratory provided us with financial and administrative information based on their operating experience.

At Stanford, Professors C. H. Oglesby of Civil Engineering and B. M. Page of Geology, with the assistance of their students, provided valuable site, geological, civil engineering and other information.

We should like to take this opportunity to thank these groups and all the other people who have contributed their time and effort to this work.

I. The General Intent of the Proposal

This proposal describes an electron linear accelerator approximately two miles long designed to produce an electron beam of high intensity in the energy range from 10 to 45 Bev. The accelerator will be powered by klystron power amplifiers operating at the design frequency of approximately 3000 megacycles per second. The electron energies attainable with this instrument will depend upon the amount of microwave power delivered by the klystrons.

The design of the proposed machine is a logical extension of the accelerator development that began at Stanford University in 1947. The largest of the Stanford accelerators has operated at energies up to 700 Mev. No fundamentally new principles are involved in the design of the proposed machine: this proposal is based on a conservative extension of present accelerator technology. Analysis of the problems of beam dynamics has shown that the dimensional, frequency, and temperature tolerances of the proposed accelerator are no more stringent than those required in the present machines. Requirements of accelerator alignment are also reasonable, since the beam can easily be "steered" at selected points. In fact, problems of alignment and geometrical stability are considerably simpler than those encountered with circular machines in the multi-Bev range.

The cost of microwave power sources is a major consideration for a large linear accelerator. Accordingly, the present design makes use of klystron amplifiers at ratings of power output and useful tube life

that are conservative by present standards. Improved tube performance will allow increased klystron power output, with a resulting increase in the electron energies attainable. The proposed machine is thus expandable in power rather than in length.

This accelerator would represent a major advance in the range of energy and intensity of particles available for physical research. The anticipated average beam current about 30 microamperes would make it an abundant source of all known artificially-produced particles and their anti-particles. The combination of high energy and a well-collimated beam would make possible the continued study of nuclear and nucleon structure in much finer detail. In addition, the proposed accelerator will increase the available electron energy to the region where study of the limitations of the present theories of electrical interactions becomes feasible. For these specific reasons we consider an accelerator of this type a very powerful instrument for high-energy physics research.

In more general terms, we believe that a diversity of instruments is of great value in itself. Much of the wealth of fundamental information uncovered in recent years is as yet imperfectly understood, and it is therefore not possible at the present time to establish a specific research program for any multi-Bev machine still in the planning stage. Because of this, we believe that diversity among several installations (in kind of particle, energy, intensity, geometrical and other beam considerations) is of fundamental importance in assuring that this basic field be comprehensively investigated.

Studies made with electron beams yield information which ideally complements that obtained with proton beams. In general, processes induced by electrons and photons are simpler in character than the

corresponding proton reactions, and are thus more readily understood in fundamental terms. The machine described here exceeds the energy economically attainable with circular electron machines, and thus offers the only known practical method of extending electron energies. In addition, the beam intensity of the proposed machine is several orders of magnitude higher than that of existing electron or proton machines used for meson production. We therefore believe that no other possibilities exist, or are in prospect at this time, for the exploration of the field of high-energy physics with electrons or photons in the 30 Bev range. Considering both the energy and the intensity of the proposed machine, we believe that such exploration will be highly effective.

Cost analyses of the project indicate a construction cost near $105 million, distributed over a period of six years. The figure includes the construction of some of the major experimental areas and facilities. The parameters of the machine proper have been chosen to minimize total costs over a ten-year operating period.

We realize fully that the construction of an installation of this kind is a major undertaking, whether in connection with an existing laboratory, university, or other institution. The proposal to locate the accelerator on the Stanford University campus is made for reasons which we believe are cogent. A suitable site, two miles long, is available on Stanford land; this is being withheld from other purposes at the present time by the Board of Trustees. The present staffs and facilities of the Department of Physics, High Energy Physics Laboratory, and Microwave Laboratory, although not at present sufficiently extensive to support such a project, are the logical sources of manpower for much of the initial planning, engineering and tests. In addition, we believe that

the ultimate research program for this machine should be integrated with the broader and more diverse activities in research and education that characterize a university such as Stanford. We do not, therefore, propose to create a new site which in time would expand and support programs other than those connected with the accelerator, but we suggest rather the incorporation of this facility within the framework of an established and expanding university program in research and teaching.

Figure I-1 shows an estimated schedule of construction of the accelerator from the date the project, if approved, would begin.

Fig. I-1. Estimated schedule of construction.

II. Description of the Proposed Installation

A. THE ACCELERATOR

1. General principles of operation of linear accelerators. - The linear accelerator dates from an early proposal by Ising (1924), and has gone through many stages of development. The most notable advance in its technology stems from wartime developments of high-powered radio-frequency power sources. Linear accelerators differ from circular accelerators in that each accelerating voltage gap is traversed only once; hence the need for a bending (guide-field) magnet is dispensed with; on the other hand, very high radiofrequency fields are needed to produce high energy in a single transit.

The operation of linear accelerators differs materially, depending on whether the particles to be accelerated are electrons or protons, and on whether the accelerating structure is of the 'traveling-wave' or 'standing-wave' type.

Proton linear accelerators generally require a longer wavelength of operation than electron machines and are therefore larger and more expensive for a given energy. At present, they have been constructed to an energy of 70 Mev. The electron linear accelerator has been developed to an energy of 700 Mev at Stanford University; construction of a 2-Bev machine is in progress at the Universite de Paris, France; and design of a machine near 1 Bev is in progress at the Ukrainian Technical Institute Kharkov, USSR. Both of the latter are believed to be patterned after the Stanford accelerator.

believed to be patterned after the Stanford accelerator.

Electron linear accelerators are considerably simpler than proton machines since the particles are traveling with a velocity essentially equal to that of light after the first few feet of acceleration. Therefore, with the exception of an 'injector' section, all further units can be of identical construction. Also, the radial defocusing forces beyond the injector become very small and only weak external focusing lenses (or no lenses at all) are needed to contain the beam.

In the standing-wave (or resonant) accelerator, the high accelerating fields are built up in a resonant structure; the particles are injected after the steady-state is reached. The structure is designed so that the particle passes successive accelerating gaps in the correct phase for acceleration. In a traveling-wave machine, the accelerating guide is first 'filled' with the accelerating field from its feed at one end of the structure. After filling, the particles are injected. The structure is designed so that the phase velocity of the field keeps up with the particle, resulting in a continuing energy gain. The two types of accelerators do not substantially differ in power economy or in their time cycle of operation; the traveling-wave machine is preferred basically because of its general simplicity.

The proposed accelerator is a direct outgrowth of the experience gathered with the Stanford accelerators. We realize that the engineering task of extrapolating the present designs to a two-mile machine is a large one; hence the machine parameters are chosen to avoid the necessity of developing new major components. This remark applies particularly to the klystron amplifiers; the power ratings and life expectancy of the tubes specified in the initial (1[illegible]-Bev or higher) phase of the proposed project

fall well within the range of present experience. Only the attainment of the highest possible energy that the accelerating structure is capable of ($\sim$ 45 Bev) will require improvement of existing klystron reliability; the lower energies are within conservative assumptions based on present klystron performance and life.

The possibility of achieving high energy under conservative assumptions of klystron performance can be understood by means of the basic linear accelerator equation:

$$V = K (P L)^{1/2} \lambda^{-1/4},$$

where V is the voltage attainable; K is a constant depending on the structure chosen but independent of power level, length, or operating frequency; P is the total power input; L is the total length; and λ is the free-space wavelength.

The total construction cost will in general be comprised of 'length-proportional' and 'power-proportional' items; an overall cost minimization can be achieved by trading length for power for a given beam voltage. This important optimizing process depends upon the assumptions made. In particular, operating costs are primarily power-proportional; if a long operating period is included in the cost analysis, then a long, low-energy-gradient, low-power machine will be favored. In this analysis, operating costs for ten years have been included in arriving at the specifications for the machine, resulting in a relatively low gradient; the resulting design can, however, capitalize on possible (and expected) future reductions in the cost of generating the microwave power, making the higher energy goal ($\sim$ 45 Bev) feasible.

The wavelength chosen for this machine is the S-band radar wavelength

(λ = 10.5 cm). The reasons for this choice are detailed in Appendix II-A.

In general, the factors which favor the choice of a longer wavelength are (1) high current, (2) less stringent mechanical tolerances, (3) higher power dissipating capacity, (4) better duty cycle. The principal factors favoring a shorter wavelength are (1) lower power cost and (2) smaller size of modulator equipment. Superposed on these factors are less tangible but important considerations such as those based on design and operating experience, availability of components and test equipment, and the like. Since consideration of these questions shows that the present operating frequency of the Stanford accelerators is very nearly the optimum, it appears wise to adhere to the present frequency value exactly.

The machine proposed here does not involve any major steps in component development; and, as will be discussed in the next section, it does not involve any substantially new assumption regarding the dynamics of the beam. Hence, the primary considerations in connection with the proposal for this machine do not deal with fundamental questions of whether such a device is operative, but rather with the problems of optimizing a design based on a synthesis of conservatively engineered components leading to reliable operation.

2. Beam dynamics. - The primary question that must be answered before seriously proposing a large accelerator is: 'Are conditions affecting the beam sufficiently understood to predict a satisfactory performance?' In considering a long machine which in its simplest aspect is a pipe 2-miles long with a bore of 7/8-in. diameter, the answer to this question might appear to be difficult. We should mention here that

in terms of total beam path this machine is very much shorter than any of the proposed circular machines. The beam passes through each section only once; hence each section can be 'trimmed' for that one passage without concern about any resonant buildup caused by accumulation of disturbing effects over successive passages.

The second major simplification of beam dynamics arises from the fact that the beam is fully relativistic after having passed through a short 'injector' section. This has two profound influences on the beam's behavior: (1) The total time of passage of one of the bunches composing the beam is independent of the beam energy since the velocity is always near that of light (c). (2) The radial forces become very small due to the near-cancellation of the electric and magnetic forces.

The first point is related to the problem of phasing the power sources to the beam. The proposed machine is essentially composed of forty machines of the type now in operation at Stanford, placed in succession. Assuming that the problem of adjusting each of these machines is handled as it is now, we are concerned only with the relative phasing of the forty 'machines. This problem can be handled by transmitting the master phasing signal by an air-filled (or vacuum) coaxial line (not waveguide) where the velocity of propagation is very nearly equal to c, as is the velocity of the beam. Hence the phase relation between the beam and power sources is invariant to change in the physical characteristics of the accelerator proper, such as those which could be caused by thermal changes or small shifts of the support structure.

The situation regarding radial beam dynamics is more complex (see Appendix II-B). If the machine were perfect, the cancellation of the radial magnetic and electric forces would be substantially complete. In that

case, the radial momentum of any electron would remain a constant of the motion while the longitudinal momentum increased linearly along the machine. As a result, the angle of beam divergence would vary inversely as the distance along the machine, and thus the beam radius would increase very slowly (logarithmically) with the distance along the axis. This slow divergence could be suppressed by very weak external magnetic lenses if desired.

Another way to understand this surprisingly favorable situation is to consider the geometry of the accelerator from the point of view of an observer moving with the electron. As is shown by simple relativistic kinematics, the length of this machine will appear to be only 3 ft to a co-moving observer, whereas the aperture remains unchanged at a diameter of 7/8 in. No more electrons are lost than the number that would miss a 7/8-in. hole at 3 ft when injected by a well-designed electron gun.

As the result of such general considerations, and supported by more detailed calculations, we conclude that from the point of view of radial and axial dynamics, a 10,000-ft accelerator will not substantially differ from a 250-ft machine. The one exception to this statement concerns the need for magnetic shielding: if no correcting coils are used, the shielding requirements can be shown to require stray fields to be reduced to 10^{-5} gauss. Although this value can be achieved by multiple high-μ magnetic shield structures, the use of occasional correcting coils reduces this problem to a minor one.

The previous remarks concerning beam dynamics do not apply in detail to the first sections of such a machine; as a matter of fact, we should like to consider, say, the first 100 ft of this machine as an 'injector.' Since the injector section does not influence the economics of the entire

machine in a substantial way, its parameters are defined by the requirements of maximum intensity, minimum radial beam momentum, and optimum bunching, rather than by the power-vs-length considerations discussed in II.A.1. It can be shown that a maximum gradient in the injector is desirable from this point of view. Radial dynamic considerations require that solenoidal (weak) focusing be employed in the non-relativistic first section (buncher) of the accelerator, which is quite short. This field will have to be tapered down along the injector in order to leave the beam with minimum radial momentum.

The limit on current output of a linear accelerator is ultimately imposed by beam loading in the accelerator. The beam currents contemplated are in the range where target dissipation constitutes a serious problem; since excessive beam loading leads to a broad energy spectrum, the proposed machine is not designed to operate as heavily loaded as short machines designed for maximum current yields would be. The currents specified for this machine correspond to about 10% - 25% conversion of the radio-frequency power into the beam power; at this figure, the beam energy spread is not in excess of that due to other causes.

3. Mechanical and electrical tolerances. - As discussed in II.A.2, the mechanical tolerances of a 10,000-ft machine need not be significantly different from those of a 250-ft machine. For reference, the permissible errors in the design values of the Stanford Mark III accelerator waveguide are:

Error in hole in disk	± 0.0002 in.
Error in diameter of guide	± 0.0002
Error in disk spacing	± 0.001
Error in disk thickness	± 0.0002 in.

These errors produce a theoretical phase shift of about 1° and decrease in

energy of less than 1%. Measurements on the present accelerators at Stanford have shown that these design tolerances can be but have not always been met.

Detailed discussion of the axial waveguide alignment tolerance is difficult at this time. Although precise alignment is desirable to assure easier operation and adjustment of the machine, it is not necessary to the success of the machine. The following set of alignment tolerances serves as a guide only; more detailed knowledge of the site conditions may make a change of these numbers advisable. This relative flexibility of alignment requirements results from our intention (see Section III) to incorporate steering coils and beam observation points at frequent intervals along the machine. Optical alignment to these tolerances can be attained by standard techniques.

TABLE II-1. Alignment tolerances

Length of section	Alignment within section	Time Duration
250 ft	± 1/16 in.	One year
	± 1/8	As long as feasible
1000 ft	± 1/4	One year
	± 1/2	As long as feasible
10,000 ft	± 1	One year
	± 5 in.	As long as feasible

As a result of the mechanical tolerances listed above for the accelerator waveguide, it is necessary to control the temperature of the accelerator to avoid drifts over short periods in excess of 2°F. The operating temperature can be set at a desired point by controlling the cooling water temperature as dictated by the economics of the heat-exchange

system. Long-range drifts in temperature are easily compensated for by shift in the driving frequency. The basic stability of the master oscillator (r-f driving system) should be better than ± 50 kc.

We should like to reiterate that none of these tolerance figures is in excess of those specified for the several currently operating accelerators.

4. The properties of the proposed machine as a tool in reasearch. - The various high-energy machines already constructed, and those in design, under construction, or under study differ in their important parameters. The important parameters are the fundamental properties: the beam energy, the beam current, and the type of particle. Other relevant parameters are: the beam geometry, the duty cycle, ease of shielding, etc.; these govern the ease with which experiments can be designed and performed.

Figure II-1 shows all of the machines now in operation or under construction plotted in terms of their design energy and current. Also shown are the machines of the FFAG (fixed-field, alternating-gradient) class; the attainable currents and energies plotted are based on estimates furnished by various sources to the National Science Foundation Panel on High-Energy Accelerators (1956). The design value of the machine proposed here is also shown; as discussed in the Specifications sections of this Proposal, the energy of this machine will be increased during development, and the intensity decreased; the proposed machine therefore appears as a slanted line on the graph.

It is clear that the machine proposed here represents a new and major step in accelerator development; we propose an advance in energy above that of any machine now in operation or under construction. In fact,

the combination of current and energy considered here is approached only by some of the machines that might potentially be available by the use of the FFAG principle. Since this Proposal is for an electron machine, the instrument will be unique in its capability for the foreseeable future.

The short duty cycle of the proposed machine is a serious detriment. Power considerations limit the fractional 'on time' of the beam to 1/2800 in the 15 - 30 Bev range, and to 1/16,700 near 45 Bev. This low duty cycle is not important in the photographic-plate techniques, and is in fact an advantage to bubble-chamber detection. However, the difficulty of designing counter experiments using coincidence and time-of-flight techniques is increased. Experience with the Stanford Mark III accelerator has shown that this difficulty can be countered effectively by careful design of such things as the shielding and by the use of magnetic spectrometers; in general terms, one is simply forced to substitute other forms of discrimination for the discrimination in time. In addition, the short pulse and the r-f fine structure of the beam make certain techniques possible; among these are counting by delayed coincidence to the beam pulse, and time-of-flight methods tying into the bunched structure of the beam. Our conclusion, based primarily on present experience, is that the short duty cycle of the beam makes impractical the use of some techniques useful with other machines but permits the application of specialized methods.

One of the primary merits of the machine proposed here concerns the favorable geometrical structure of the beam. Both an external electron beam and a high-energy γ-ray beam are useful; there is no 'extraction' problem. The beam diameter will be about 1/4 in., with an angular

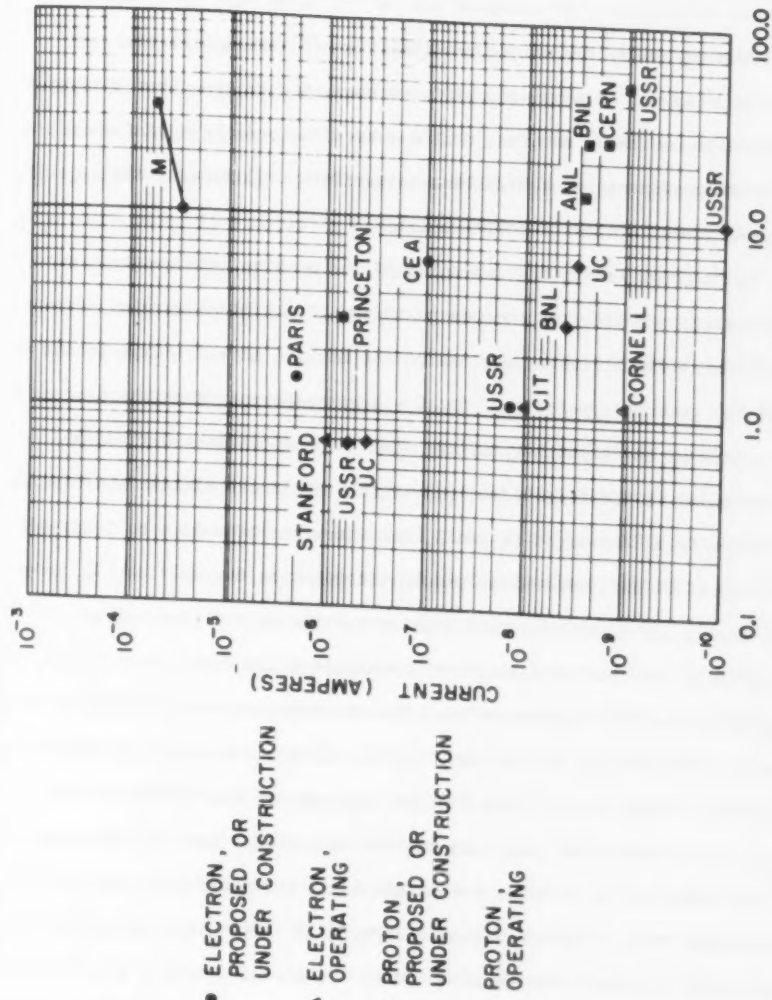

Fig. A-1

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divergence of only 10^{-5} radian (two seconds of arc). This geometrical quality of the beam permits, among other things, a wide dispersal of experimental facilities. We consider this a very important advantage since, on the one hand, the unique possibilities of the machine will make mandatory its use by many scientific workers, and on the other hand, the small values of cross sections at these energies and the need for very accurate measurements at high beam intensities will necessitate experimental installations of poor mobility.

Due to the high energy and intensity of the machine, the question of adequate radiation protection becomes an integral part of the design of the experimental facilities as well as of the machine itself. Experiments can be of two general types: (a) 'thick'-target experiments in which a large fraction of the capability of the beam to produce secondary radiation is expended in the target, and (b) 'thin'-target experiments where the radiation from the target is small, and where the beam must be 'buried' in a well-shielded enclosure after passage through the target.

The design described here incorporates facilities for both types of operation in the initial accelerator construction proposal. The emerging beam from the accelerator is split into several beams by magnetic-deflection systems, and is then 'piped' via earth-shielded vacuum lines into the target areas. Thick-target experiments can be carried out in target houses where the beam bombards the target in a heavily-shielded enclosure; openings in the shield can then admit secondary particles into the target house. Space is provided for thin-target experiments where analyzing equipment can be moved in an arc around a target in the beam.

B. SCIENTIFIC OBJECTIVES

The motives underlying a new accelerator project are in general divided between a general desire to extend the range of accelerator parameters such as energy and current into previously unattained regions, and specific scientific objectives. We feel that the justification for this accelerator is singularly strong on both counts. We wish to add that it has been the rule rather than the exception that in the time interval between inception of an accelerator project and the beginning of actual research, the logical scientific program has shifted materially from that originally envisaged.

Any high-energy accelerator is useful in the following general categories: (1) as a controlled source of artificially-produced particles which are otherwise only produced in very low intensity from cosmic rays; (2) as a source of particles to explore nuclear structure and to study the interactions of these particles in nuclear matter; (3) as a tool to study the basic production process in the creation of particles. Added to these, in the case of electron accelerators, is: (4) as a tool to study the high-energy limits of quantum electrodynamics.

The machine described in this Proposal should prove to be a more abundant source of artificially-produced particles than any of the machines now operating or under construction. Figure II-2 shows the thresholds for production of the particles now known for electrons and protons; we note that in terms of threshold the range of electron energies from 15 to 45 Bev corresponds to an energy range of 19.5 to 47 Bev for protons. Production cross sections for such particles are about 100 times larger for protons than for photons. This factor is modified by the fact that the useful target thickness for protons is of

the order of a 'nuclear mean free path,' while for photons it is of the order of the radiation length. For light elements the nuclear mean free path is roughly three times shorter than the radiation length. By employing a light target, the total secondary-particle yield is roughly 30 times smaller than the corresponding heavy-particle yield. In terms of secondary-particle yields (and also of neutron yields, which affect shielding considerations), the current values shown in Fig. II-1 for the electron machines should be 'de-rated' by a factor of 30 relative to proton machines; however, the energy values should be shifted up corresponding to the same center-of-mass energy, as shown in Fig. II-2; this has been done in Fig. II-3. It is seen that from the point of view of particle production the proposed machine is more powerful in each energy range than any others with the exception of some of the potential FFAG designs.

The study of 'weakly-coupled' particles is a special area in particle production where the use of a high-intensity, high-energy electron machine offers unique possibilities. These are particles whose strongest mode of production would be electromagnetic production (production by photons radiated by electrons), but which can also be decay products of strongly-coupled particles. In the latter class is the μ-meson; due to the (not-understood) selection rule preventing the τ-meson from decaying into electrons, the main source of μ-mesons is π-μ decay. Were it not for this accidental circumstance, electromagnetic production - as recently observed with the Stanford accelerator - would be the dominant mode of production. Consequently it is quite possible that a family of such particles, not 'fed' from strongly-coupled systems, has escaped our observation.[1] Due

[1] The particle of 525 electron masses, recently reported by workers in USSR, may be in this category.

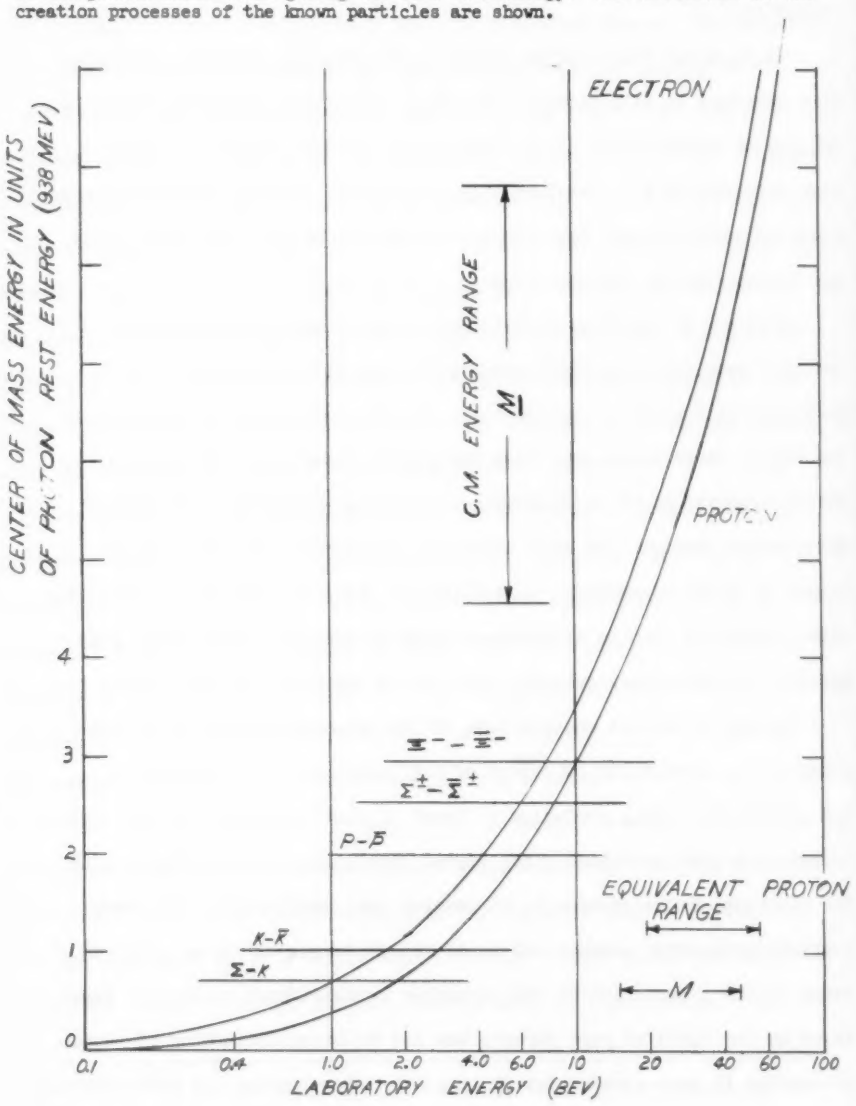
to the smallness of electromagnetic pair-production cross sections, high-intensity electron beams will be required to study these possibilities.

It is clear that studies involving high-energy electron scattering will continue to be fruitful. The study of nuclear structure will give results of increasingly higher resolution at these energies. However, high intensity and a clean, collimated electron beam are absolutely necessary to such studies since the cross sections become very small while the angular detail becomes high.

Problems in electron scattering on nuclei and nucleons have in the past been fruitful since unknown structures are explored with a known (electromagnetic) interaction. At these energies we are entering the region where deviations from the present formulation of quantum electrodynamics might be expected; scattering experiments are doubly interesting because they also become of interest in the study of the limits of electrodynamics; in addition to electron scattering on nuclei, other processes such as electron-electron scattering, large-angle pair production, and bremsstrahlung, also become important in this respect.

Another potential contribution of the proposed machine is to the study of the production processes of new particles. In contrast to the problem of simply producing a 'beam' of such particles, we are concerned here with questions going beyond obtaining a large particle flux. The photoproduction process is in general less complex than the heavy-particle production process and lends itself frequently to analysis in terms of the interaction of the particles produced with nucleons. Experience in the field of pion physics has led to an understanding of photoproduction in much greater detail than has been possible for heavy-particle

Fig. II-2. Plot of available center-of-mass energies, in units of the proton rest mass (938 Mev), vs laboratory energies of electron and proton machines. The proposed range of the M accelerator is shown, and also the range of an equivalent proton accelerator giving the same c.m. energy. The thresholds of the creation processes of the known particles are shown.



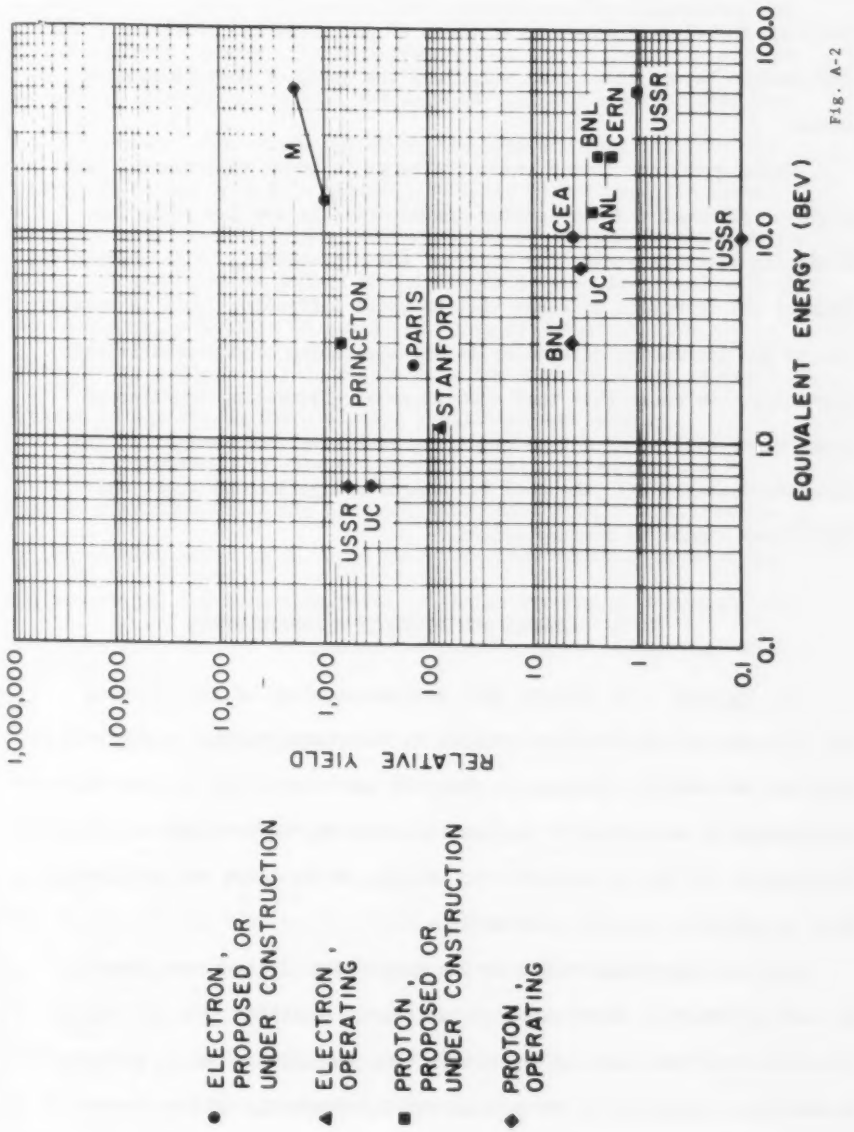

RELATIVE YIELD
1,000,000
100,000
10,000
1,000
100
10
1
0.1
0.1
1.0
10.0
100.0
EQUIVALENT ENERGY (BEV)
M
USSR
UC
PRINCETON
PARIS
STANFORD
BNL
CEA
UC
ANL
BNL
CERN
USSR
USSR
● ELECTRON, PROPOSED OR UNDER CONSTRUCTION
▲ ELECTRON, OPERATING
■ PROTON, PROPOSED OR UNDER CONSTRUCTION
◆ PROTON, OPERATING

Fig. A-2

production. In addition, the external electron beam is a special tool, as experience with the present accelerators shows: the ratio of cross sections for electron-induced to those of photoproduced processes gives information beyond that obtainable from the study of photoproduction alone.

These questions form a major challenge to known experimental techniques. Although the accelerator characteristics are favorable for obtaining suitable yields for study of these processes, it is certain that many of the detection problems will be quite difficult; this is notably due to the increasing difficulty in distinguishing highly-relativistic particles. We anticipate that a continuously-increasing fraction of experiments will be of a type requiring extensive instrumentation and accurate measurement; the need for adequate experimental space and facilities cannot be overemphasized.

C. GENERAL ADMINISTRATIVE ARRANGEMENTS

1. General. - We propose that the construction of this machine and carrying out the research program be undertaken through a contract to Stanford University. We propose that the Director of the project be responsible to a Board of Directors appointed by the President of Stanford University. It may be desirable to include on the Board representatives from neighboring academic institutions.

Since the operating budget of the proposed activity is comparable to that of Stanford University, it is clearly indicated that all administrative functions such as accounting, purchasing, personnel, grounds maintenance, shops, etc., be carried out independently of the present University functions. Hence, the costs of such service functions shall

be a direct part of the project.

It is understood that the faculty members and students of the Department of Physics will participate actively in the scientific work of the project. However, it is expected that the project will attract a group of scientists who will not be a part of the academic staff of the University. The unique nature of the proposed facility puts the laboratory in the role of a national facility even though its formal operation would remain as the responsibility of the University-appointed Board. It shall be the policy of this Board to make the facilities of the laboratory available to qualified scientific workers from any institution, subject only to maintaining the quality of the research program as limited by the available facilities and funds.

It is proposed that the new facility limit its activities to fields of science which are directly associated with the utilization of the accelerator. It is hoped that the close relation between the laboratory and the remaining parts of the University will provide the necessary diversity of background for other original scientific work.

2. Site considerations. - It is proposed that the machine be constructed on a site, estimated at 400 acres, located within the boundaries of the lands owned by Stanford University. Stanford has suitable land available for the project, and this is being withheld from other use at the present time by the Board of Trustees.

The site choice is based on many considerations. The proximity of the site to the participating University departments is a major advantage which will be reflected in a shorter 'start-up' period as well as in better ultimate research programs. Despite the size of the undertaking, we do not consider the proposed installation as an isolated

laboratory; rather, we believe that the continuing close relations between the laboratory staff and other University departments will materially contribute to the success of the project. We do not propose that a new, complete installation devoted to physical and chemical research be developed, but suggest that this major research tool be integrated within an environment already active in research and teaching.

The construction schedule of the proposed machine covers six years. Of this period, a large fraction of the first and second years' efforts will go into the construction of laboratory, office, and other buildings. Also, it is intended that engineering design and component testing be started as soon as practical. For these purposes, some of the existing laboratory facilities can be made available; in particular, the Mark II and Mark IV accelerator installations offer facilities for component testing. Since such testing is of great importance for conservative engineering of the machine, we believe that a considerable saving of time in the construction period can be realized by a site selection allowing a continuous transition to the new facilities.

In evaluating the site we must realize that radiation shielding is a serious concern in this undertaking. We are well aware of the fact that almost all present high-energy accelerators are experiencing difficulties in varying degrees due to inadequate shielding. These arise from a combination of factors: (a) beam exceeding initial expectations, (b) lack of full knowledge of physical phenomena involved in the shielding problem at the time of design, (c) increased conservatism in the allowable radiation levels. Although we do not claim a full understanding of all the basic effects underlying the shielding problem, we believe that the site chosen makes possible a conservative approach.

The shielding specifications arise from these requirements: (a) 'Acute' radiation hazards should be eliminated. (b) The radiation levels in areas occupied by personnel in activities connected with the project should not exceed a given tolerance. We have chosen 30 mrem/40-hr week and 3 neutrons/cm^2/sec as this figure; this is 1/3 the level recommended by the Committee on Radiation Protection in 1956. (c) The radiation level in areas outside that allocated to the project corresponds to less than 10 r/$\sim$ 30 years of continuous operation. This is the so-called 'doubling dose' - a level corresponding to the amount received by the average person from natural sources (cosmic rays and natural radioactivity) and from medical x-rays.

These requirements lead to certain minimum shielding thicknesses between project personnel and potential radiation sources and also to a very large dimension for the target areas. The quantitative analysis of these problems is discussed in Appendix II-C, and the numerical values obtained are tabulated in the section on quantitative specifications of the machine. These specifications call for 35 ft of earth shielding between the accelerator and accessible areas, and for a distance of at least 500 ft from the experimental target facilities to the laboratory boundaries.

The site chosen on Stanford University property is compatible with both these requirements. It is proposed to run the accelerator in a 10-ft diameter tunnel separated from an equipment tunnel by the required 35 ft of earth. The target area is located in a valley of adequate size surrounded by hills. The accelerator site is located in a hilly section of Stanford land; the tunnel is thus underground by a variable depth.

We believe that the tunnel system described is a reasonably economical solution for developing the available site compatible with the radiation shielding requirements. The cost of the tunnel corresponds to about $/sq. ft. of available floor space;[1] we believe that as a combined figure for shielding and laboratory space this is not unreasonable.

Our detailed site studies have also included other possibilities; for example, a site in which cut-and-fill rather than tunnel techniques would be used has been studied in detail. Our present site recommendation is made over the other possible schemes on the basis of cost, the possibility of a level accelerator structure, and the ease of radiation shielding.

No site involving extensive tunnel construction can be considered final until extensive boring exploration has been completed. We anticipate that such boring information might necessitate some shift in the exact location of the accelerator. The present site selection is based on geological information derived primarily from soil tests and surveys by the Utah Construction Company, to whom we are greatly indebted. The studies leading to the present site selection were carried out with the active help of the Bechtel Corporation and the Utah Construction Company.

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[1] See section on cost estimates for details (Sec. V).

III. Design Policies

This section summarizes the basic design principles on which the more detailed specifications of Section IV have been based and which affect the cost estimates of Section V. Section IV will describe a possible solution compatible with these policies; some of the numerical specifications are, of course, subject to changes resulting from a more extensive analysis of the design problems.

A. GENERAL POLICIES

1. No fundamentally new principles are to be employed in the proposed machine: the proposal is to be based on a conservative extension of present accelerator technology.

2. The design must be based upon klystron amplifiers performance, power output ratings, and useful tube life that are conservative by present experience. As tube performance improves, the attainable klystron power output will increase, and therefore the electron beam energy of the accelerator will also increase. We thus consider the proposed accelerator to be expandable in power rather than in length.

3. In the choice of parameters as governed by cost, operatings costs over a ten-year period are to be included in arriving at an optimum design.

4. With the exception of an "injector" section, all further units of the machine are to be of identical construction. This will enable mass production methods to be employed during the construction phase and will greatly simplify servicing of the machine components.

a) The first 100 ft of the machine shall be considered as an injector, i.e., its gradient and other specifications shall be such as to provide the maximum beam current rather than the maximum energy or economy of operation.

b) The machine is to be divided into sectors (say 250 ft) which are independently adjustable for optimum performance. This implies that either a pulsed inflector and deflector system be provided for each sector, or that a retractable gun and deflection magnet be available, or that another means be developed to accurately phase the klystrons within a sector.

c) Components shall be used whose performance is well established at the time of the design freeze. New components will be developed only where necessary, then thoroughly tested before being incorporated in the machine. This is not meant to imply that more efficient methods for producing existing components will not be sought.

5. Test vehicles, including a short accelerator, are to be provided as soon as possible for testing new components and for the purpose of training personnel to operate and service the machine.

6. The power sources shall be disconnectable during full operation of the machine so that components can be replaced without disrupting machine operation.

7. The accelerator waveguide shall be manufactured to conform to a specified frequency so that additional sections can be fabricated without reference to the accelerator itself.

8. The beam shall be extracted only at the end of the machine; no 'taps' of beams along the machine appear desirable.

9. The experimental areas shall have several locations so that bombardments can be performed in one area while 'setup' work is being safely carried out in the remaining locations.

10. The experimental areas shall be designed to be flexible enough to permit development of additional specialized sites to use the beam.

B. OPERATING CHARACTERISTICS

1. The machine is to be operated on a 4-shift (24 hrs/day, 7-day week) basis.

a) The accelerator proper is to be designed for minimum maintenance requirements. All auxiliary equipment, controls, etc.,are to be located in space well shielded from the accelerator to permit maintenance during full operation.

2. The radiation level in work areas is intended to be less than 30 m rem/week.

3. The radiation level in areas outside the project boundaries is to be less than 10 r/30 years. See appendix II-C for further details on radiation tolerances.

C. THE PHASES OF DEVELOPMENT

1. This proposal covers the construction of the accelerator, the associated laboratories, and the bombardment facilities (end station) in two phases, Stage I and Stage II.

The installed power capacity, water circulation, and land requirements for both phases are to be provided initially. The phases differ primarily in (1) the number of feed points of r-f power (i.e., the number

of klystrons used to power the accelerator), and (2) the number of developed beam areas in the terminal facility (end station). The primary differences are:

	Stage I	Stage II
Number of klystrons supplying power to the accelerator	240	920
Beam Energy	10-20 Bev	~ 45 Bev
Repetition rate	360 cps	60 cps
Number of developed beams	3	6

2. The transition from Stage I to Stage II is to be achieved in a continuous manner without any major shutdown of the machine.

IV. Accelerator Specifications

A. INTRODUCTION

The machine specifications to follow have evolved from the design policies outlined in Section III of this proposal, and from other general considerations discussed in Sections I and II. It should be emphasized that the particular solution presented here is a possible and a realistic one based on a conservative extension of present accelerator technology. No major attempt has been made to completely optimize the various designs at this time; rather a solution has been found which is technically feasible and which provides a reasonable basis for arriving at the cost estimates given in Section V.

The degree of detail given in the specifications varies considerably. Some of the parameters are identical with those of existing components (e.g., the klystron specifications given in Appendix IV-B) and hence may be quoted rather precisely. Other specifications characteristic of the longer machine (e.g., instrumentation and control) are necessarily less exact, and are therefore presented in more general terms.

The design is a logical extension of the development of linear accelerators at Stanford University since 1947. Much of this work has been reported in a summary article by Chodorow, Ginzton, Hansen, Kyhl, Neal and Panofsky.[1] The cost of microwave power sources is a major consideration in selecting the power input vs length of the accelerator

[1] R.S.I. 26, 134, 1955.

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for a given energy. Accordingly, this design incorporates klystron amplifiers at ratings of power output and useful tube life that are conservative by present experience. As tube performance improves, increased klystron power output will result in higher attainable beam energy. It is for this reason that we consider the proposed accelerator to be expandable in power rather than in length. The proposed length is 10,000 feet.

For initial operation, the accelerator is to be powered by 240 klystron amplifiers, each delivering 6 megawatts of peak power to the accelerator for a 2.5 microsecond duration at a repetition rate of 360 pulses per second. The corresponding beam energy will be 10 Bev. These klystrons will be sealed-off versions of the tubes presently used by the Stanford machines, although some mechanical redesign will be necessary to facilitate mass production and to allow rapid interchange of the tubes. As tube techniques improve the klystrons will be operated at correspondingly higher power levels until an operating level in the vicinity of 22 megawatts is attained. Beam energy would then be approximately 20 Bev. At this point the number of klystrons powering the accelerator will be increased to 920, yielding a beam energy of 45 Bev. However, the repetition rate will then be reduced to 60 pulses per second, so that the initial installed power capacity for Stage I operation will be adequate for Stage II operation.

B. DESCRIPTION OF THE PROPOSED ACCELERATOR

The accelerator proper will be a 4-inch diameter disk-loaded copper waveguide made in 10-foot sections. For operational and tune-up purposes, the accelerator will be organized into sectors nominally 250 feet long, such that each sector may be operated as an independent accelerator with its own gun and beam extraction system. The accelerator will be comprised of 40 such sectors totaling 10,000 feet in length.

The accelerator proper will be housed in a tunnel approximately 10 feet in diameter. At the 10,000 foot point, the electron beam will be magnetically extracted and distributed into various areas of the end station for experimental studies.

Parallel to the accelerator tunnel, at a lateral distance of approximately 35 feet, a second tunnel (the klystron tunnel) will house the klystrons, the klystron modulators, the vacuum pumps, the control equipment and other auxiliary equipment. All equipment that may need frequent servicing will be located in this klystron tunnel since the machine will operate 24 hours per day. This proposed continuous operation necessitates that equipment located in the accelerator tunnel be built

and installed in a manner which will allow rapid servicing or replacement so as to minimize the "off" time of the accelerator.

With the exception of certain routine adjustments such as tuning accelerator sectors or lubricating motors, all servicing shall consist of replacement of entire units or major parts of units. Trouble-shooting and repair of extracted units will then be performed by technicians in a shop area outside of the tunnel.

The main control area will be located in or adjacent to the klystron tunnel and will have instrumentation for controlling the 40 sectors as integral units only. It will, however, also have rudimentary monitors for checking the performance of each klystron or of each major unit and will have a switch for turning each unit off or on. The actual number of operating controls for the accelerator, however, shall be minimized.

A detailed description of the tunnels, their contents, and the control and instrumentation of the accelerator is given in Appendix IV-A.

A summary of the Design Parameters of the proposed accelerator is given in the following tables.

(See project data sheet for tables)

As previously noted, a site for the accelerator is available on Stanford-owned land which is being withheld from other use at the present time. While it is likely that the actual width of the accelerator structure, consisting of the two parallel tunnels, would be about 70 feet, it is believed desirable to have available a strip of land 1000 feet wide for the first 10,000 feet. The area involved is 230 acres. The beam extraction and experimental areas would increase the length to a total of 12,600 feet and would increase the area required by approximately 150 acres, making a total of 380 acres. A complete description of the site and building requirements is given in Appendix IV-C.

C. THE BEAM EXTRACTION AND EXPERIMENTAL AREAS

Since the primary purpose for building the accelerator is to provide a beam of high energy electrons for the study of basic problems in physics, the utility of the accelerator depends to a great extent upon the facilities provided for using the electron beam.

In particular, there must be a sufficient area available for research so that any foreseeable experiment can be performed. This requirement has been met by the proposed site which provides about six million square feet of area for experimental purposes. Such a large available area greatly enhances the potential value of the accelerator.

In addition to sufficient research space, it is important to provide as useful an electron beam as possible. Two considerations are significant in this respect. First, the electron beam should be small in cross-section, and its energy spread should be known and adjustable. Second, it is important that the electron beam be readily delivered to different

experimental set-ups. This latter requirement is particularly important because of the large apparatus which will be used in the research programs at multi-Bev energies. Many weeks will be required to install such equipment, and an accelerator that could not deliver a beam to several different experimental locations would be severely limited in its usefulness. A companion consideration to this is that radiation shielding between experimental areas should be sufficient so that workers may have access to one experimental location while the electron beam is being used at another location.

A satisfactory fulfillment of all these requirements is obtained by using the beam-deflecting system shown in Fig.IV-1. This system has been termed "The Beam Switchyard." The Beam Switchyard delivers four doubly-deflected beams plus the undeflected beam. The doubly-deflected beams have been energy analyzed and may be directed to any experimental apparatus along their paths. The importance of the second deflection is to clear the beam of neutral radiation produced at the energy-defining slits. The beams are sufficiently separated so that adequate shielding can be installed around the various experimental locations. Such double-deflection systems are now being satisfactorily operated at Stanford.[1,2]

In order to adequately plan the Beam Switchyard and the experimental area beyond (to be called "The End Station"), some possible experiments have to be considered. From the point of view of shielding (and hence, to a large extent, of the geometry of the experiment) there are two types of experiments: thick target, and thin target. In the thick-target case, there must be adequate shielding around the target (~ 22 ft of concrete, see Appendix II-C). In the thin-target case, it is only

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[1] W. K. H. Panofsky and J. A. McIntyre, Rev. Sc. Inst. 25, 287 (1954).

[2] K. L. Brown, Rev. Sc. Inst. 27, 959 (1956).

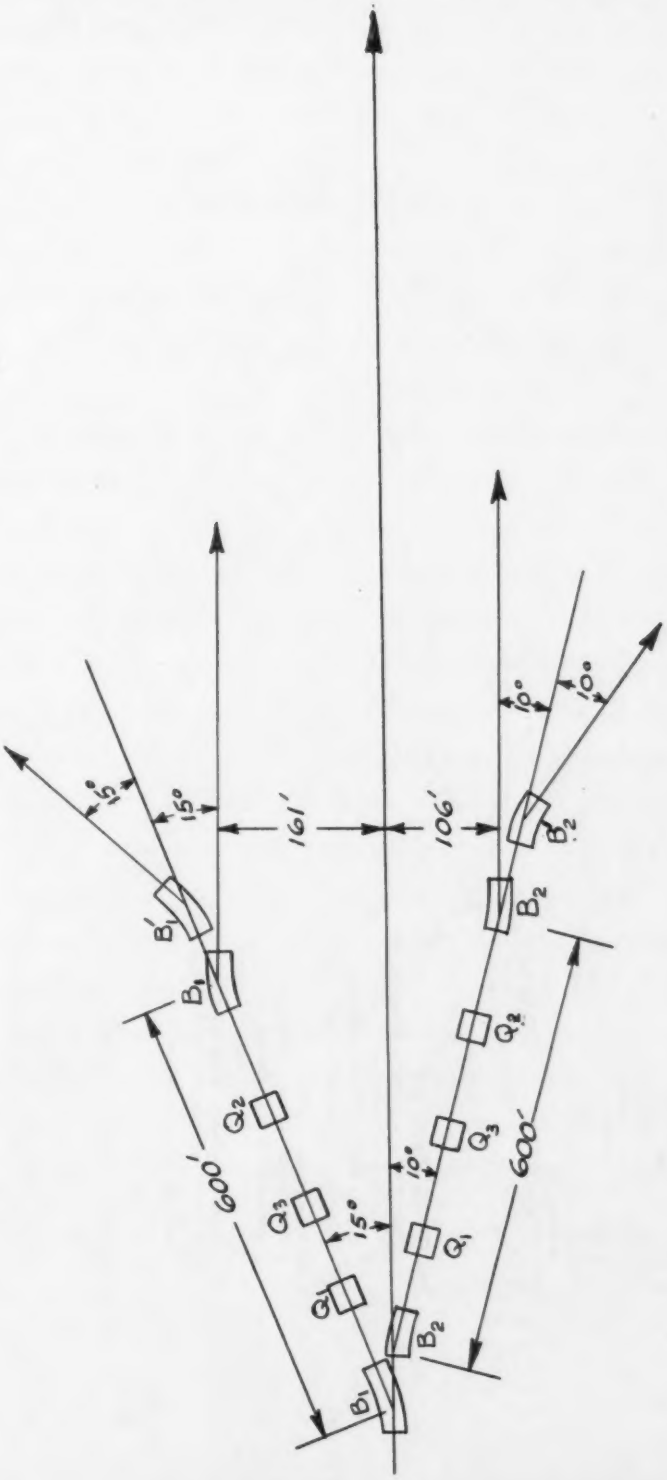

Fig. IV-1. The Beam Switchyard

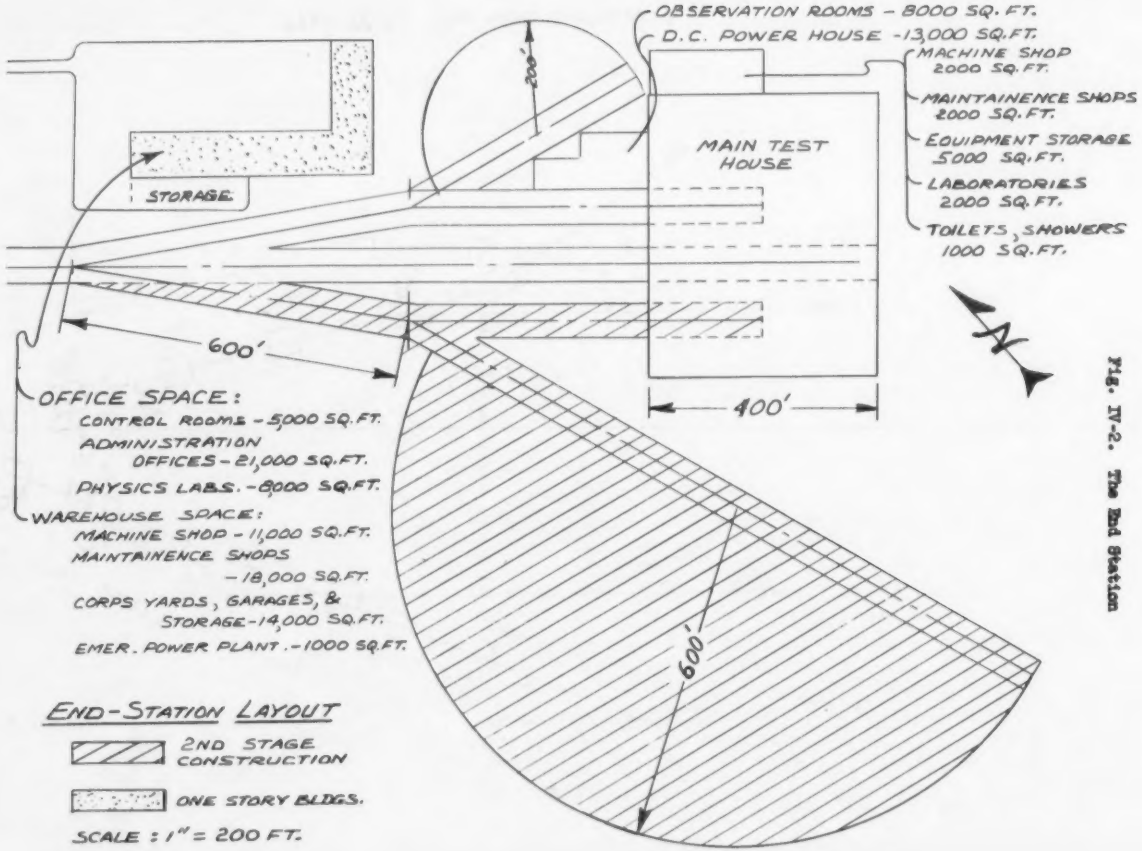
OBSERVATION ROOMS - 8000 SQ. FT.
D.C. POWER HOUSE - 13,000 SQ. FT.
MACHINE SHOP 2000 SQ. FT.
MAINTAINENCE SHOPS 2000 SQ. FT.
EQUIPMENT STORAGE 5000 SQ. FT.
LABORATORIES 2000 SQ. FT.
TOILETS, SHOWERS 1000 SQ. FT.
MAIN TEST HOUSE
STORAGE
200'
600'
400'
600'
N
OFFICE SPACE:
CONTROL ROOMS - 5,000 SQ. FT.
ADMINISTRATION OFFICES - 21,000 SQ. FT.
PHYSICS LABS. - 8,000 SQ. FT.
WAREHOUSE SPACE:
MACHINE SHOP - 11,000 SQ. FT.
MAINTAINENCE SHOPS - 18,000 SQ. FT.
CORPS YARDS, GARAGES, & STORAGE - 14,000 SQ. FT.
EMER. POWER PLANT - 1000 SQ. FT.
END-STATION LAYOUT
2ND STAGE CONSTRUCTION
ONE STORY BLDGS.
SCALE: 1" = 200 FT.

Fig. IV-2. The End Station

necessary to provide that personnel not be struck by the beam; therefore heavy shielding is not usually required. The importance of this experimentally is that counting apparatus may then be rotated about the thin target without interference from an intervening shielding wall.

Allowance has been made for both types of experiments. The three center electron beams are covered by an experimental building (main test house) with shielding placed around the beams (see Fig. IV-2). Thick targets may be placed in the beams at any point in the building. The building is quite long (400 ft) because the 90° center-of-mass angle transforms to 12° at 45 Bev. Thus, for example, an anti-proton beam produced by a thick target would emerge at about 12°, and a long building is required if the beam is to be utilized. A 100-ton crane with 75 ft overhead clearance covers the entire building for handling of the shielding and magnets.

The two outer beams leaving the Beam Switchyard are reserved for thin target experiments. In these experiments a double-focusing magnetic system would be mounted on a carriage that can be rotated about the target. For the left-hand beam a 200-ft radius area is available for electron scattering at 15 Bev, or for other thin target experiments (see Fig. IV-2). The 600 ft radius area reserved for the extreme right-hand beam would be suitable for 45 Bev electron-scattering experiments.

D. CONSTRUCTION PROGRAM

While it was necessary to consider initially the many possible experiments that might be conducted with the accelerator in order to select an appropriate research site, there is no immediate need to plan for complete development of the research area. On the contrary, because of the rapid development of research techniques it seems unwise to plan

in any more detail than necessary the research that would be undertaken eight or more years from now. Consequently, only an initial program will be proposed at this time. This program will be designated Stage I, and the rest of the research area development will take place as experiments are designed. Thus, development of the research area will proceed on a continuous basis.

The facilities to be developed are indicated in Fig.IV-2. The unshaded areas are those planned for initial installation. This comprises the following:

1. The undeflected beam.

2. The left doubly-deflected beam. This includes all of the magnets in this beam, as shown in Fig. IV-1. However, the deflection system for the extreme left-hand beam will not be extended beyond the last deflecting magnet until the 200 ft spectrometer is designed. The other left-hand beam entering the main test house will be developed however. The magnets for the deflected beams are to be built for the maximum energy of 45 Bev, even though the accelerator will not deliver this energy initially. This procedure is proposed so that the entire deflecting system will not have to be dismantled in the future when the accelerator energy is slowly increased to its maximum value. Since the beam is small in cross-section, the magnet apertures are small; as a result, the 45 Bev magnets are not prohibitively costly. Also, precise energy control of the beam is desired so that the only feasible deflecting system appears to be the conventional iron magnets, even extrapolating ten to fifteen years into the future.

3. The main test house. Since two of the three beams entering the house are to be developed initially, it seems advisable to build the entire house in Stage I.

4. Beam shielding in the test house for the developed beams. This is expensive but essential for safety.

The initial development of the Beam Switchyard and End Station is a necessary complement to the accelerator construction. In order to tune up and evaluate the accelerator performance, for example, a deflecting system is required. Also, if there is not to be a long delay between the completion of the accelerator and the inauguration of research, a research facility must be available at the time of accelerator completion. Such a facility is represented by the development proposed here for Stage I construction.

V. Construction Cost Estimates

This section is concerned with the estimating of costs for developing (1) a 2-mile long accelerator, powered by 480 6-Mw klystrons, with a beam-switching system and target areas, (2) the site, with tunnels, buildings, outdoor utility areas and the necessary general facilities, and (3) utilities and space for research operation. It does not include any costs of research operations or of specific research equipment; these are discussed in Section VI.

We were exceedingly fortunate in obtaining the contribution of extensive assistance from the Utah Construction Company and the Bechtel Corporation with respect to site and plant. Each firm consulted with us about our specifications, studied the civil and geological aspects of the various sites at Stanford, advised us concerning the best ways of using the site selected, and prepared cost estimates of the buildings and grounds development. Bechtel Corporation concentrated its attention on preparing a plan which used cut-and-fill construction to house the accelerator for most of its length, whereas the Utah Construction Company developed the accelerator housing by tunneling. The staff preferred the tunnel scheme, and so the estimates of plant development given in this proposal are those which were prepared by Utah.

Valuable suggestions concerning the development of the End Station target house and area were made by Bechtel Corporation. The staff included these in their specifications to Utah, and they are reflected in the latter's costs.

The site and plant costs may be presumed to be the most reliable estimates in our proposal, since they were given by a competent firm with

a large experience. Several comments need to be made about the other estimates.

Klystron costs were developed by the Stanford group. A study of commercial production costs, made at our request by Varian Associates, tends to support our own estimate. We thus believe the klystron figures to be reliable.

The estimates on accelerator construction are based on extrapolations from the cost information, often incomplete, accumulated in the building of the following accelerators, all developed at Stanford: Mark II (38 Mev), Mark III (700 Mev), Mark IV (80 Mev), Stanford Hospital (6 Mev), Michael Reese Hospital (25 Mev), and Argonne Memorial Hospital (50 Mev). We have not been able to explore more than superficially the possibility of reducing the cost of building the accelerator by means of specialized tooling for quantity production instead of using techniques we have used in our shops. It seems probable that a large saving could be made this way, but a study of this must necessarily follow rather than precede authorization of the project.

Again, we have not had enough experience with escalation costs in technical development work to consider ourselves competent to estimate their effect on the cost of designing, building and testing a large accelerator beginning, say, two years hence and finishing six years later. The Utah estimates do include a cost escalation factor; those estimates which we have prepared do not on the whole, but it is our belief that the absence of such a factor is more than offset by the absence of a discount for specialized tooling for quantity production. The only escalation used in our staff figures is in the average rates used for staff labor. These are an extrapolation to 1960 from current rates in the Stanford area.

The estimates reflect three simple premises. One is that the project would be a Stanford University project. Another is that its size and character would require it to be largely self-sufficient. The third is that Stanford would conduct it under agreements with the sponsoring agency which would involve no financial gain or loss to the University. In this connection there will be certain costs to be covered which are not included in our estimates. It seems pointless to attempt to state these now. They would be identified and evaluated by both parties during negotiation of a sponsoring instrument, and could not conceivably represent any significantly large part of the total cost.

Finally, we have attempted to show in the estimates all of the information which we believe is needed for an appraisal of the project. We have not included any cost detail for the sole purpose of justifying or assisting the verification of our estimating work, and we have not attempted to predict or anticipate all of the possible questions which interested parties may raise.

Inasmuch as the estimating committees prepared their labor requirements as actual work hours, these have been extended by factors to cover vacations and sick leave, supervision and general tool maintenance for the various groups of technicians, and are so reported in the estimates. This was not done in the case of engineers or of administrators and assistants, where the number required was stated on an over-all basis. Holidays have been excluded from the number of labor hours in a labor man-year.

Costs of all kinds have been listed under one of two categories: Purchases, or Staff Labor. By purchases we mean materials or services, including labor at times, to be procured from others by means of purchase orders or subcontracts. Staff Labor refers to labor to be supplied by persons to be employed by Stanford on the staff of the project. The decision whether to accomplish certain work by Staff Labor or by Purchases was determined in general by the availability of an adequate commercial source, or according to the importance of direct communications between the engineering staff and the technicians. In some cases, however, the decision was quite arbitrary. It follows that the division of costs between the two categories represents merely the best present estimate.

Assuming for the moment that the estimate of staff labor required is reasonable, it will be apparent (Schedule E) that it has not been considered important at this time to engage in scheduling work in detail in such a way as to provide a more nearly constant level of staff during the construction period. One part, however--the personnel for administration and general services--has been estimated so that, at full complement, it would provide for either a reasonably averaged full construction effort or for a research operations requirement.

SCHEDULE A-1

GENERAL DESIGN, ENGINEERING AND TEST

Staff labor hours:		
Engineers:		
General specifications	52,708	
Klystron tubes and factory	73,008	
Power supply design	73,008	
Control and instrumentation	111,540	
Specific design and components testing	496,880	
	807,144	
	@ $4.25 avg.	
		$ 3,430,362
Supporting staff:		
Draftsmen	380,250	
Laboratory technicians	1,342,283	
Machinists	380,250	
Electricians	190,125	
Electronics technicians	190,125	
	2,483,033	
	@ $3.25 avg.	
		8,069,857
		11,500,219
Purchases		1,990,000
		$13,490,219
Memo, total hours	3,290,177	

SUMMARY

CONSTRUCTION COST ESTIMATE

	Staff Labor	Purchases	Total	Ref. Schedule
A. Accelerator design, fabrication and test:				
1. General design, engineering and test	$11,500,219	$ 1,990,000	$13,490,219	A-1
2. Power facilities	3,835,000	7,213,000	11,048,000	A-2
3. Prototype units	651,310	902,500	1,553,810	A-3
4. Accelerator proper	3,386,906	3,040,000	6,426,906	A-4
5. Klystron amplifiers, 6 Mw	1,431,586	1,187,880	2,619,466	A-5
6. Beam Switchyard and End Station	244,943	505,030	749,973	A-6
7. Control and instrumentation	1,395,410	5,352,813	6,748,223	A-7
	22,445,374	20,191,223	42,636,597	
B. Equipment:				
1. Fabrication and test equipment	338,026	4,661,974	5,000,000	B-1
2. Hauling and handling equipment	---	974,000	974,000	B-2
3. Furniture, storage and office equipment	---	310,000	310,000	B-3
	338,026	5,945,974	6,284,000	
C. Administration and general services	3,967,072	3,511,000	7,478,072	C
D. Tunnels, buildings and grounds development	---	21,672,000	21,672,000	D
E. Reimbursement to University for other costs	*	*	*	-
TOTAL+	$26,750,472	$51,320,197	$78,070,669	
F. Memo: The costs of additional work to attain a fully complemented accelerator for Stage II level operation are not developed in full. The costs which have been estimated, and which exclude space needs, equipment other than fabrication and test gear, cost of administration and general services, or other University costs, are as follows:				
Components fabrication and installation	$5,477,114	$3,680,353	$9,157,467	
Fabrication and test equipment	84,960	49,481	134,441	
	$5,562,074	$3,729,834	$9,291,908	F

*To be determined by negotiation.

+For staff labor and cost analyses, see Schedules E, E-1, E-2 and E-3

SCHEDULE A-2

POWER FACILITIES

	Purchases		Staff Labor Hours
P. G. and E. line	$ 310,000		-
Substations	1,338,000		-
4.16 KV feeders	820,000		-
DC cable, accelerator	10,000		5,000
Modulators and power supplies	4,020,000		1,006,250
Special wiring	715,000		168,750
		$ 7,213,000	1,180,000 @$3.25 avg.
		3,835,000	-
		$11,048,000	

SCHEDULE A-3

PROTOTYPE UNITS

	Purchases		Staff Labor Hours
Components and installation	$ 520,000		200,403
Reinforced removable ferrite concrete shielding	382,500		-
		$ 902,500	200,403 @$3.25 avg.
		651,310	-
		$ 1,553,810	

SCHEDULE A-4

ACCELERATOR PROPER

	Purchases		Staff Labor Hours
Accelerator structure with vacuum and water cooling (fabrication, component testing and installation):			
Accelerator pipe	$ 439,000		654,000
r-f couplers	21,500		96,250
Waveguide sections	467,500		68,125
Windows	24,000		50,000
Vacuum manifold	251,000		58,750
Cooling water manifold	164,000		58,750
Accelerator support	53,000		50,000
Cooling water recirculation system	1,620,000		6,250
		$3,040,000	1,042,125 @ $3.25 avg.
		3,386,906	←
		$6,426,906	

SCHEDULE A-5

KLYSTRON AMPLIFIERS

	Purchases		Staff Labor Hours
Klystron amplifier tubes, 6 Mw (fabrication and processing):			
630 Klystrons (approx. 1 1/3 initial complement)	$ 441,000		435,488
480 Shields and focusing coils	746,880		5,000
		$1,187,880	440,488 @ $3.25 avg.
		1,431,586	←
		$2,619,466	

Memo: Klystrons for prototype accelerators are not funded here, but under Prototypes.

SCHEDULE A-6

BEAM SWITCHYARD AND END STATION

	Purchases		Staff Labor Hours
Deflection system	$ 254,750		46,688
Vacuum system	134,280		9,054
Signal and communications	78,500		19,625
Cooling water recirculation system	37,500		--
		$ 505,030	75,367 @ $3.25 avg.
		244,943	-
		$ 749,973	

SCHEDULE A-7

CONTROL AND INSTRUMENTATION

	Purchases		Staff Labor Hours
Consoles and wiring	$ 574,143		340,757
r-f system	2,577,830		19,500
Trigger systems	76,400		2,500
Inflection and deflection systems	544,000		29,000
Auxiliary systems	1,580,440		37,600
		$5,352,813	429,357 @ $3.25 avg.
		1,395,410	-
		$6,748,223	

SCHEDULE B-1

FABRICATION AND TEST EQUIPMENT

	Purchases		Staff Labor Hours
A. Klystron factory:			
Parts fabrication and inspection shops	$ 412,000		2,750
Tube assembly	162,150		8,014
Tube processing	363,000		75,575
Air conditioning and ventilation	35,000		-
		$ 972,150	86,339 @ $3.25 avg.
		280,602	←
		1,252,752	
B. Accelerator proper:			
Electroforming facilities	364,450		
Machine tools	424,600		
r-f test equipment	37,200		
Air conditioning	1,000		
Installation	70,675		17,669
		897,925	17,669 @ $3.25 avg.
		57,424	←
		955,349	
C. All other fabrication and test equipment		2,791,899	
		$5,000,000	

Recapitulation:

Purchases	$4,661,974
Labor, hours and cost 104,008 @ $3.25	338,026
	$5,000,000

SCHEDULE B-2

HAULING AND HANDLING EQUIPMENT

	Purchases
Overhead cranes and trolleys, End Station test house, Beam Switchyard, and Research Machine Shop (Utah Construction Company estimate)	$ 879,700
Overhead crane, rails and supports, Prototypes Lab. (not specified to Utah Co.)	20,000
Tunnel transportation, battery operated vehicles (Utah Construction Co. estimate)	44,300
Trucks, fork lifts, etc.	30,000
	$ 974,000

SCHEDULE B-3

FURNITURE STORAGE AND OFFICE EQUIPMENT

	Purchases
Bookkeeping machines, calculators, etc., for Accounting Office	$ 45,000
Calculators, etc., for other administrative and general services	10,000
Furniture, cabinets, racks, shelving, and office equipment	255,000
	$ 310,000

SCHEDULE C

ADMINISTRATION AND GENERAL SERVICES

Administrators, assistants and section heads, $3.45 hr. avg.,	354,900 hours	$1,224,405	
Secretaries, clerks, helpers, $2.10 hr. avg.	1,306,032 "	2,742,667	
	1,660,932 "		$3,967,072
OASI tax and compensation insurance costs		625,000	
Group life insurance and retirement plan costs		450,000	
Plant security posts		364,000	
Plant maintenance costs		875,000	
Communications		287,000	
Other operating costs		800,000	
Travel		110,000	
			3,511,000
			$7,478,072

SCHEDULE D

TUNNELS, BUILDINGS AND GROUNDS DEVELOPMENT*

Estimated by

UTAH CONSTRUCTION COMPANY, SAN FRANCISCO, MARCH 8, 1957

1.	Engineering and Design:				
	(a) Engineering, design and architectural			$1,094,300	
	(b) Geological surveys and explorations			53,000	
					$ 1,147,300
2.	Underground Construction:				
	(a) Klystron tunnel			5,980,000	
	(b) Accelerator tunnel			1,930,000	
	(c) Cross drifts and connections between klystron and accelerator tunnels			1,160,000	
	(d) Ventilation shafts			110,000	
	(e) Tunnel work in switchyard area			297,000	
					9,477,000
3.	Plant and Surface Construction:				
	(a) Page Mill Road crossing		$ 365,000		
	(b) Open cut work at 10,000-ft. point		40,000		
	(c) Open cut work for End Station		685,000		
				1,090,000	
	(d) Building Construction:	Sq. Ft.			
	1. Unfinished warehouse	15,500	93,000		
	2. Semi-finished warehouse	35,000	445,000		
	3. Special warehouse (target house)	200,000	2,720,000		
	4. Shop space	77,000	1,113,000		
	5. Laboratory space	42,000	885,000		
	6. Offices	24,000	546,000		
		393,500		5,802,000	
	(e) Shielding Bunkers:				
	1. Inside target house		2,000,000		
	2. Steel culvert and backfill		425,000		
				2,425,000	
	(f) Outdoor Utility Areas			485,000	
	(g) Parking Area			45,000	
	(h) Roadways, setbacks, etc.			290,000	
					10,137,000
4.	General:				
	(a) Site preparation, facilities, etc.			420,000	
	(b) Security fencing			125,200	
	(c) Tunnel lighting			217,800	
	(d) Site and Security lighting			78,800	
	(e) Landscaping and planting			68,900	
					910,700
	TOTAL -				$21,672,000

*For description, see Appendix IV-C.

SCHEDULE E

ESTIMATED LABOR USE SCHEDULE
IN MAN YEARS

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Total
1. General design, engineering and tests	78	206	288	356	347	347	1,622
2. Power facilities	0	60	120	220	180	2	582
3. Prototype units	5	30	40	20	4	0	99
4. Accelerator proper	0	0	0	206	206	102	514
5. Klystron amplifiers	0	0	21	88	88	20	217
6. Beam Switchyard and End Station	0	0	0	18	19	0	37
7. Control and instrumentation	0	0	21	84	84	24	213
8. Fabrication and test equipment	0	34	17	0	0	0	51
	83	330	507	992	928	495	3,335
9. Administration and general services	18	89	178	178	178	178	819
Total staff -	101	419	685	1,170	1,106	673	4,154
Percentage -	2	9	16	29	27	17	100

SCHEDULE E-2

CONSTRUCTION STAFF LABOR* TRADES ANALYSIS

	Hours	Man Years
Engineers	807,144	398
Machinists	1,886,867	930
Welders and brazers	52,225	26
Electroplaters	16,813	8
Tube technicians	231,052	114
Laboratory technicians	1,342,283	662
Electricians	1,042,036	514
Electronics technicians	332,502	164
Accelerator technicians	101,995	50
Plumbers	23,667	12
Steel and sheet metal men	541,438	267
Riggers	3,653	2
Draftsmen	380,250	188
	6,761,925	3,335

*Labor for development of tunnels, buildings and grounds is not included: subcontract work. For analysis of administration and general services labor, see Schedule E-3.

SCHEDULE E-1

SUMMARY, LABOR HOURS AND COST
OTHER THAN ADMINISTRATION AND GENERAL SERVICES*

		Hours	Rate	Cost
1.	a. Gen. design, eng. and test-Professional	807,144	$4.25	$ 3,430,362
	b. Gen. design, eng. and test-Technical	2,483,033	3.25	8,069,857
		3,290,177		11,500,219
2.	Power facilities	1,180,000	"	3,835,000
3.	Prototype units	200,403	"	651,310
4.	Accelerator proper	1,042,125	"	3,386,906
5.	Klystron amplifiers	440,488	"	1,431,586
6.	Beam Switchyard and End Station	75,367	"	244,943
7.	Control and instrumentation	429,357	"	1,395,410
8.	Fabrication and test equipment	104,008	"	338,026
	Hours @$3.25	5,954,781		19,353,038
	Hours @$4.25	807,144		3,430,362
	TOTAL -	6,761,925		$22,783,400

*Buildings and Grounds Development excluded: subcontract work.

SCHEDULE F

ADDITIONAL COSTS OF CONSTRUCTION
OF ACCELERATOR TO STAGE II LEVEL

	Purchases		Staff Labor Hours
A. Components fabrication and installation:			
1. Power facilities:			
Substations	$ 15,000		
DC cable, accelerator	10,000		5,000
Modulators and power supplies	2,650,000		662,500
		$ 2,675,000	667,500
			@ $3.25 avg.
		2,169,375	←
		4,844,375	
2. Control and instrumentation:			
Consoles and wiring	69,504		11,256
r-f system	1,518,000		11,000
Auxiliary systems	88,880		2,800
		1,676,384	25,056
			@ $3.25 avg.
		81,432	←
		1,757,816	
3. Klystron amplifier tubes:			
630 Klystrons (440 + spares)	441,000		435,488
440 Shields and focusing coils	684,640		4,400
		1,125,640	439,888
			@ $3.25 avg.
		1,429,636	←
		2,555,276	
Sub-total (A) -		9,157,467	
B. Fabrication and test equipment:			
Klystron processing stations	84,960		15,225
		84,960	@ $3.25 avg.
		49,481	←
Sub-total (B) -		134,441	
TOTAL -		$9,291,908	

Memo: The costs of additional work to attain a fully complemented accelerator for Stage II level operation are not developed in full. The costs which have been estimated exclude space needs, equipment other than fabrication and test gear, cost of administration and general services, or other University costs.

SCHEDULE E-3

LABOR, ADMINISTRATION AND GENERAL SERVICES

1. Full complement, per year:

	Administrators and Assistants		Secretaries, Clerks, helpers		Total		
	Hours	No.	Hours	No.	Hours	No.	A.
Director's Office	6,084	3	12,168	6	18,252	9	
Business Office	6,084	3	12,168	6	18,252	9	
Legal Office	2,028	1	4,056	2	6,084	3	
Personnel Office	10,140	5	10,140	5	20,280	10	
Purchasing Office	20,280	10	30,420	15	50,700	25	
Accounting Office	8,112	4	73,008	36	81,120	40	
Budgets and estimating	6,084	3	6,084	3	12,168	6	
*Property control	6,084	3	20,280	10	26,364	13	
Library	2,028	1	4,056	2	6,084	3	
Photography and duplicating	2,028	1	6,084	3	8,112	4	
*Telephone and mail	-	-	10,140	5	10,140	5	
Staff secretaries	-	-	44,616	22	44,616	22	
*Receiving, delivery and stores	2,028	1	38,532	19	40,560	20	
*Safety and first aid	2,028	1	6,084	3	8,112	4	
Mobile stock maintenance	-	-	4,056	2	4,056	2	
Information	4,056	2	2,028	1	6,084	3	
TOTAL, One Year -	77,064	38	283,920	140	360,984	178	

2. Estimated need, construction period:

Year 1 ~ 10%	8,112	4	28,392	14	36,504	18	
Year 2 ~ 50%	38,532	19	141,960	70	180,492	89	
Year 3 100%	77,064	38	283,920	140	360,984	178	
Year 4 100%	77,064	38	283,920	140	360,984	178	B.
Year 5 100%	77,064	38	283,920	140	360,984	178	
Year 6 100%	77,064	38	283,920	140	360,984	178	
TOTAL, Six Years -	354,900	175	1,306,032	644	1,660,932	819	

*3-shift operation needed

VI. Research Operating Cost Estimate

This section presents an analysis of the operating costs of the two-mile electron linear accelerator once it has attained regular operation for research purposes. These costs do not constitute a part of this proposal but are included for reference, so that the long-range commitments involved in undertaking this construction project may be evaluated.

The main body of the proposal and the cost estimates of Section V cover the following items: (a) development of the site, plant and general facilities; (b) construction of the accelerator; (c) target areas and beam-switching magnets. The main body does not contain specific items of experimental equipment although some fabrication and test equipment used in the construction of the machine might be useful to research afterwards. It is intended that such additional experimental equipment be built up under the operating budget.

This section is not concerned with the detailed transition from the construction to the operating budget. We feel that the timing of this transition would depend on a large number of circumstances which are not predictable at this time. Hence the cost estimates give only an annual rate of expenditure once full operation is reached.

Cost estimates are based on Phase I operation (15-30 Bev). The transition to Phase II is predicated on the expected lessening of r-f power costs and will be undertaken only if this expectation is realized. Hence Phase II operating costs are not expected to be materially different from those of Phase I, but cannot now be analyzed.

In setting specifications for the machine parameters, we have taken the operating costs over a ten-year period into account in arriving at

optimum design figures; in this sense, analysis of the operating costs is a part of the design of the accelerator.

To a large extent, operating costs depend on the volume of research work to be supported and the energy and current of the accelerator, rather than on the detailed design of the accelerator or even the type of accelerator. This operating budget, therefore, should not be viewed as being related in a very direct way to the specific machine, but as an indication of the cost of carrying on work in this energy and current region.

The only item which is specifically a singular cost of a linear accelerator of this type is the klystron costs, which are estimated at about $1,700,000 a year; large as it is, this item is far from being the dominating cost in the operation of an accelerator.

Operating costs are basically divisible into the following classes:

A. Regular, continuing costs:
   1. Machine operation
   2. Costs of the research program

B. Non-recurrent costs of major capital improvements, e.g.:
   1. Construction funds for machine, site and facilities improvements
   2. Costs of single large pieces of research equipment (large bubble chamber, magnets, etc.)

It is clearly impossible to estimate the 'non-recurrent' improvement items on a rational basis at this time; but in predicting the long-range operating costs involved in this proposal it would also be misleading to ignore them. The costs included in these categories are based on extrapolation of the operating experience of the Bevatron, Cosmotron, and Stanford Mark III linear accelerator rather than on items of research equipment known at this time.

Regular operating costs are based on (a) extrapolation of the Stanford experience; (b) analysis of klystron production costs (a study of possible commercial production costs, which was made at our request by Varian Associates, tends to support our own estimates); (c) direct analysis of power and other utility requirements of the specific installation; (d) scientific equipment costs based on Stanford and UCRL experience. Costs are estimated in terms of wage scales extrapolated to 1960, in conformity with the practice adopted in the construction budget.

SUMMARY

RESEARCH OPERATING
COST ESTIMATE (ANNUAL)

		Purchases	Staff Labor Cost	Total
1.	Machine operation and maintenance	$ 4,015,000	$ 1,815,000	$ 5,830,000
2.	Research	810,000	1,694,600	2,504,600
3.	Large research equipment, 1/2 of 2-yr. budget	2,600,000	-	2,600,000
4.	Capital improvements, 1/4 of 4-yr. budget	1,675,000	-	1,675,000
		9,100,000	3,509,600	12,609,600
5.	Administration and general services	877,049	826,000	1,703,049
6.	Reimbursement to University for other costs, to be determined by negotiation	*	*	*
	TOTAL -	$ 9,977,049	$ 4,335,600	$14,312,649

* See explanation, next to last paragraph of introduction to Section V.

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RESEARCH OPERATING COST
ESTIMATE (ANNUAL)

1.	**Machine operation and maintenance:**			
	a. **Klystron factory:**			
50	Tube technicians	$330,000		
10	Electroplaters and other specialists	66,000		
6	Draftsmen - engineers	39,600		
25	Technicians - baking and processing	165,000		
25	Machinists and brazers	165,000		
116			$ 765,600	
	Materials and equipment		965,000	
				$1,730,600
	b. **Other machine costs:**			
46	Accelerator operators[1]	303,600		
50	Machinists and brazers	330,000		
63	Accelerator technicians	415,800		
159			1,049,400	
	Power		1,200,000	
	Other materials and equipment		1,850,000	
				4,099,400
275	**Sub-total** -			5,830,000
2.	**Research:**			
10	Senior physicists	100,000		
40	Junior physicists	160,000		
62	Machinists and brazers	409,200		
25	Research technicians	165,000		
25	Electronics technicians	165,000		
25	Electricians, installation	165,000		
25	" , maintenance	165,000		
8	Engineers	68,800		
31	Draftsmen	204,600		
23	Laborers[2]	92,000		
			1,694,600	
	Power		210,000	
	Other materials and equipment		600,000	
274	**Sub-total** -			2,504,600
3.	**Large research equipment:**			
	Two-year budget:			
	Large magnetic spectrometer		1,200,000	
	Bubble chamber, or equivalent		2,000,000	
	Research magnets		1,000,000	
	Other		1,000,000	
			5,200,000	
	× 50% annually -			2,600,000

[1] 24-hour a day, 365 days a year operation, crews of 10 men, plus fill-ins.

[2] 24-hour a day, 365 days a year operation, crews of 5 men, plus fill-ins.

4.	Capital improvements - plant and machine:			
	Four-year budget:			
	Additional observation house		$1,500,000	
	DC Generators		200,000	
	Machine improvements		2,000,000	
	Shielding changes, End Station		3,000,000	
			6,700,000	
	× 25% annually -			$ 1,675,000
5.	Administration and general services:			
	38 Administrators, assistants, section heads	$266,000		
	140 Secretaries, clerks, helpers	560,000		
			826,000	
	OASI tax and compensation insurance	106,515		
	Group life insurance and retirement plan costs	126,534		
	Plant security posts (3)	84,000		
	Plant maintenance costs	280,000		
	Communications	60,000		
	Other operating costs	200,000		
	Travel	20,000		
			877,049	
178	Sub-total -			1,703,049
727[3]	TOTAL (except other Univ. costs[4]) -			$14,312,649

[3]Average rates used:

Senior physicists	$ 10,000
Junior physicists	4,000
Engineers	8,600
Administrators, assistants, section heads	7,000
Laborers, secretaries, clerks, helpers	4,000
All others	6,600

[4]See entry 6 on SUMMARY SHEET.

APPENDIX II-A

Factors Affecting Choice of Wavelength

The choice of wavelength in the proposed accelerator is governed by many considerations, including of course a natural conservatism in undertaking a program of this size.

A detailed analysis (applying primarily to low-energy accelerators [< 10 Mev]) of the wavelength choice for electron accelerators has been given by Chu and Ginzton (ML-274). We shall discuss here only the more general factors; in particular, we shall ignore questions involving optimum choice of 'internal parameters' such as disk spacing and dimensions, optimum number of feed points, power recirculation *vs* no power circulation, etc.

Ignoring such detailed questions, the scaling laws are as given in Table II-A-1. Obviously there is no single 'figure of merit' that can be formally maximized as a function of the wavelength. The competing elements are, primarily: (a) High current and longer duty cycle favor longer λ. (b) Longer λ is expensive in power and energy storage, and is also more limiting in terms of maximum gradient.

Hence the choice of wavelength in a high-energy machine is limited basically in the direction of large λ by the price one is willing to pay for high current; in the direction of small λ by whether the machine can be built at all considering power sources and mechanical tolerances.

TABLE II-A-1. Wavelength scaling laws

Quantity	Scaling law	Remarks
Q	$\lambda^{1/2}$	
Filling time	$\lambda^{3/2}$	
Power for fixed electron energy and fixed accelerator length	$\lambda^{1/2}$	
Energy storage in modulator for fixed electron energy and fixed accelerator length	λ^{2}	Assuming fixed ratio of beam time to filling time and fixed repetition rate.
Power dissipation capability for accelerator of given length	λ	
Power dissipation capability of power sources	λ^{2}	
Electron beam current	λ^{2}	If limited by aperture.
	$\lambda^{1/2}$	If limited by beam loading for fixed energy and length.
Voltage gradient	$\lambda^{-1/4}$	Approximate; empirical.
Mechanical tolerances	$\lambda^{1/2}$	Absolute tolerance in dimensions.
	$\lambda^{-1/2}$	Relative tolerance.
Duty cycle (for fixed energy and length)	$\lambda^{3/2}$	If limited by average power dissipation in power sources (assuming a fixed number of sources).

APPENDIX II-B.

Beam Dynamics

A. GENERAL CONSIDERATIONS

We shall not present here a comprehensive consideration of the beam dynamics of the electron linear accelerator; for details, the reader is referred to the publications of Chu (ML-140), Chu and Hansen (J. App. Phys.), Chodorow et al. [Rev. Sci. Instr. 26, 134 (1955)], and Smars (ML-252). From these and other papers the following relevant facts emerge:

1) With the exception of the first few (not completely relativistic) sections of a linear accelerator, the motion is longitudinally neutral, i.e., neither phase stable nor phase unstable; the relative phase between particle and fields depends on the accuracy of control of the phase and phase velocity within the accelerating structure and the other radio frequency components.

2) In the non-relativistic section, phase stability and bunching action are attainable at the expense of radial defocusing. This defocusing can be counteracted by external weak or strong focusing lenses.

3) No complete analysis has been made of the theoretical phase acceptance of the non-relativistic entrance section of an electron linear accelerator with external lens focusing which takes into account the coupling between longitudinal and radial dynamics. Analyses of particular cases have shown that a phase acceptance in excess of 120° is easily possible; final bunching angles depend on the feasible length of the non-relativistic section.

4) The current capacity of an electron accelerator (particularly at short wavelength) is limited by electron beam loading. In an accelerator specifically designed for highest current operation, very heavily loaded operation is possible; in this Proposal a loading of the order of 10% is adopted.

5) An ideal continuous linear accelerator guiding electrons approaching the velocity of light has very simple properties regarding the radial behavior of the beam. The radial electric force is balanced by a magnetic force which is $-\beta^{-2}$ times the electric force, where β is the particle velocity in units of the velocity of light. As the result, the radial momentum is very nearly a constant of the motion of the particles; since the longitudinal momentum increases linearly with the axial distance, the angle of the beam with the axis varies as γ^{-1} and the beam radius increases logarithmically with the axial distance.

6) The logarithmic radial divergence does not lead to a serious beam loss. Also, residual gas scattering effects are small. In addition, very small strong-focusing lenses are sufficient to reduce these residual losses to zero; such lenses lead, however, to somewhat increased final angular divergence (for details see ML-202).

B. SPECIFIC PROBLEMS OF INTEREST IN A VERY LONG ACCELERATOR

1. The Effect of Phase Errors and Nonuniform Accelerating Fields on the Radial Dynamics. Let us use x and r for the axial and radial variables, and adopt the notation:

$$\zeta = z/\lambda,$$

$$\eta = r/\lambda,$$

β = phase velocity of fields in guide,

$\alpha(z) = \lambda eE / m_0c^2$,

$E(z)$ = crest value of electric field,

m_0c^2 = rest energy of particle,

θ = phase angle of particle relative to crest ($\theta > 0$ for particle ahead of crest);

let a dot over a letter denote $\partial / \partial \zeta$. The radial equation, neglecting space charge and correct to linear terms in η, but otherwise independent of field shape (assumed only to have axial symmetry), is (see Eq. (6.59b), ML-140):

$$\frac{d}{d\zeta}(\gamma \dot{\eta}) = \frac{\pi \alpha \eta}{\beta \zeta}(1 - \beta \dot{\zeta}) \sin \theta - \frac{1}{\dot{\zeta}} \frac{\eta}{2} \frac{\partial \alpha}{\partial \zeta} \cos\theta. \qquad (1)$$

We shall not assume that β, the phase velocity in the guide, will tend to unity; instead, we will assume (as corresponds to the real situation) that β will be governed by the imperfections in the guide structure. However, β and the phase angle are related by

$$\frac{d\theta}{d\zeta} = 2\pi\left(\frac{1}{\beta} - \frac{1}{\zeta}\right). \qquad (2)$$

Simplifying and ignoring the radial variation of α (which would only affect nonlinear terms in η, which are already neglected), we obtain in the limit of $\dot{\zeta} \longrightarrow 1$,

$$\frac{d}{d\zeta}(\gamma \dot{\eta}) = -\frac{1}{2}\frac{d}{d\zeta}(\alpha \eta \cos\theta) + \frac{1}{2}\frac{d\eta}{d\zeta}(\alpha \cos\theta) + \frac{\pi \alpha \eta}{\gamma^2} \sin\theta. \qquad (3)$$

The last term is the usual term giving a radial focusing or defocusing term depending linearly on the radial variable but varying as γ^{-2} due to the near cancellation of electric and magnetic fields. We will not

consider this term further since its effect has been discussed. The remaining terms become:

$$\frac{d}{d\zeta}\left[\dot{\gamma}\,\eta + \frac{1}{2}\,\alpha\,\eta\cos\theta\right] = +\frac{1}{2}\frac{d\eta}{d\zeta}\,(\alpha\cos\theta)\,. \tag{4}$$

Let us integrate this expression over the full length of the accelerator, starting and ending in field-free space:

$$(\dot{\gamma}\,\eta)_{final} = (\dot{\gamma}\,\eta)_{initial} + \frac{1}{2}\int_{initial}^{final} \alpha\cos\theta\,\frac{d\eta}{d\zeta}\,d\zeta \tag{5}$$

$$\cong (\dot{\gamma}\,\eta)_{initial} + \frac{1}{2}\frac{\gamma_{final}}{\zeta_{final}}\,(\eta_{final} - \eta_{initial}), \tag{6}$$

since $\alpha\cos\theta$ is the energy gain per wavelength. Hence the effect of field nonuniformities and phase variations is equivalent to a final beam divergence corresponding to a focal length given by

$$1/F = 1/2L \tag{7}$$

where L is the length of the entire machine. This effect is thus negligible. We retain the conclusion, previously demonstrated under more limiting conditions, that the radial momentum proportional to $\gamma\,\eta$ is a constant of the motion.

2. Stray Magnetic Fields. Neglecting the effects discussed previously, the influence of a transverse component B of magnetic field is governed by the equation

$$(d/d\zeta)\,(\dot{\gamma}\,\dot{\zeta}) = b \text{ (for } \gamma \gg 1), \tag{8}$$

where b is the dimensionless ratio $eB\lambda/cm_0$; this integrates to

$$r_{final} = r_{initial} + (b/\alpha)\, L; \qquad (9)$$

hence, if $L = 3\times10^5$ cm,

$\alpha = 1.5$,

$r_{final} - r_{initial} < 0.1$ cm,

then

$$b < 9\times10^{-7} \quad \underline{or} \quad B < 0.8\times10^{-4} \text{ gauss.} \qquad (10)$$

Hence magnetic shielding to this mean value is required. This is quite feasible, although the use of steering coils is probably more suitable since they are needed anyway to correct mechanical misalignments.

APPENDIX II-C.

Radiation Shielding

A. GENERAL CONSIDERATIONS

1. Principles. The shielding design of the proposed accelerator involves a number of problems; not all of them can be fully analyzed at the present time. In fact, some of the physical input data for such calculations are quite incomplete. Fortunately, this ignorance does not affect materially the specifications for the transverse shielding of the accelerator; shielding problems ahead of the beam occur only in the target area, where conditions are quite flexible.

In principle the various physical phenomena occuring when a 45-Bev electron penetrates into matter are not clearly separable since such an electron will generate an extensive shower containing both soft and penetrating components. To arrive at working figures for shielding, however, we shall divide the processes into the following categories:

1) Photoneutrons in the 10-80 Mev region produced by the γ-rays in a 'soft' (i.e., photon-electron) shower;
2) Photoneutrons produced in the energy region above 80-Mev neutron energy;
3) Photomeson production and the resulting production of nucleons;
4) Production of μ-mesons from π-meson decay;
5) Penetration of the soft electron shower;

6) Penetration of the nucleon cascade;

7) Neutron air scattering.

2. Radiation Tolerances. The recommendations of the Committee on Radiation Protection (1956) and of the National Academy of Sciences-National Research Council Report (1956) specify maximum doses equivalent to the following:

1) 100 mr per 40-hr working week for 'radiation workers,' i.e., personnel voluntarily engaged in work involving some radiation exposure.

2) One tenth of the dose rate under (1) for areas adjacent to the installation in question.

3) A dose of about 10 r / 30 yrs to the 'population at large.' This is roughly the 'doubling dose,' i.e., that dose at which the exposure would be double that incurred from natural sources and diagnostic x-rays.

Since the general tendency has been toward more conservative radiation tolerances, we are adopting here for design purposes the following tolerances:[1]

1) 30 mr/40-hr working week for 'radiation workers';

2) A level equal to natural background radiation (or 0.002 r per elapsed week) for all areas outside the project boundaries will be maintained. This is about a third of the 'doubling dose.'

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[1] By 'r' we mean rem, i.e., the roentgen dose divided by the relative biological equivalent for the particles in question.

For fast neutrons, a dose rate of 30 mr / 40-hr week corresponds to 3 neutrons/cm^2/sec.

At minimum ionization, 1 electron/cm^2 = 3×10^{-8} r. Hence the 'radiation worker' tolerance corresponds to 7 minimum-ionization electrons per cm^2 sec.

3. Properties of Materials. Table II-C-1 gives the relevant characteristic numbers of the shielding materials considered. Densities are nominal and consequently the thicknesses must be pro-rated according to the densities used.

Neutron half-value thicknesses are tabulated for neutrons of energy > 1 Bev. These thicknesses are for the absorption (not scattering) of neutrons of energy in excess of 1 Bev and do not include any cascade effects. The energy variation of the neutron half-value thicknesses in concrete is given in Fig. II-C-1.

4. Machine Parameters. For purposes of calculation we shall use:

E_0 (primary electron energy) = 45 Bev,

Primary electron beam = 2×10^{13} electrons/sec = 3 μa.

B. CALCULATIONS ESTABLISHING THE SHIELDING REQUIREMENTS TRANSVERSE TO THE ACCELERATOR

Of concern here are reaction products feeding out from the core of the principal shower. The radiation in the shower core affects the 'in-line' shielding primarily.

1. Low-energy Neutrons (0 - 80 Mev) Produced by γ-rays. Let the cross

section for forming a neutron by a photon of energy k be given by $\delta(k)$. A primary electron of energy E_0 gives rise to a 'track length' $\pi(E_0,k)\,dk$ of photons in the energy range from k to k + dk.

The yield per electron of neutrons is then

$$Y = \frac{N_0 X_0}{A} \int \delta(k)\, \pi\,(E_0,k)\, dk, \qquad (1)$$

where N_0 is Avogadro's number, X_0 is the radiation length, A is the atomic number, and $\pi(E_0,k)$ is assumed to be given in radiation lengths.

Using the relation, obtained from shower theory, that

$$\pi(E_0,k) = 0.6\, E_0/k^2\ ; \qquad (2)$$

and also that approximately the integrated cross section for the production of 'giant resonance' neutrons is given by

$$\int \delta\,(k)\, dk \approx 0.12\, NZ/A \quad \text{(Mev barn)}; \qquad (3)$$

we obtain, assuming that $\delta\,(k)$ peaks sharply near $k = k_0 = 20$ Mev, the relation

$$Y = 0.1 N_0 X_0 (NZ/A^2)\ (E_0/k_0^{\,2}) \times 10^{-24}\ . \qquad (4)$$

This gives yields as shown in Table II-C-2; the values given there contain slight additional corrections taken from Levinger.[1]

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[1] J. S. Levinger, Nucleonics, 64 (May 1950).

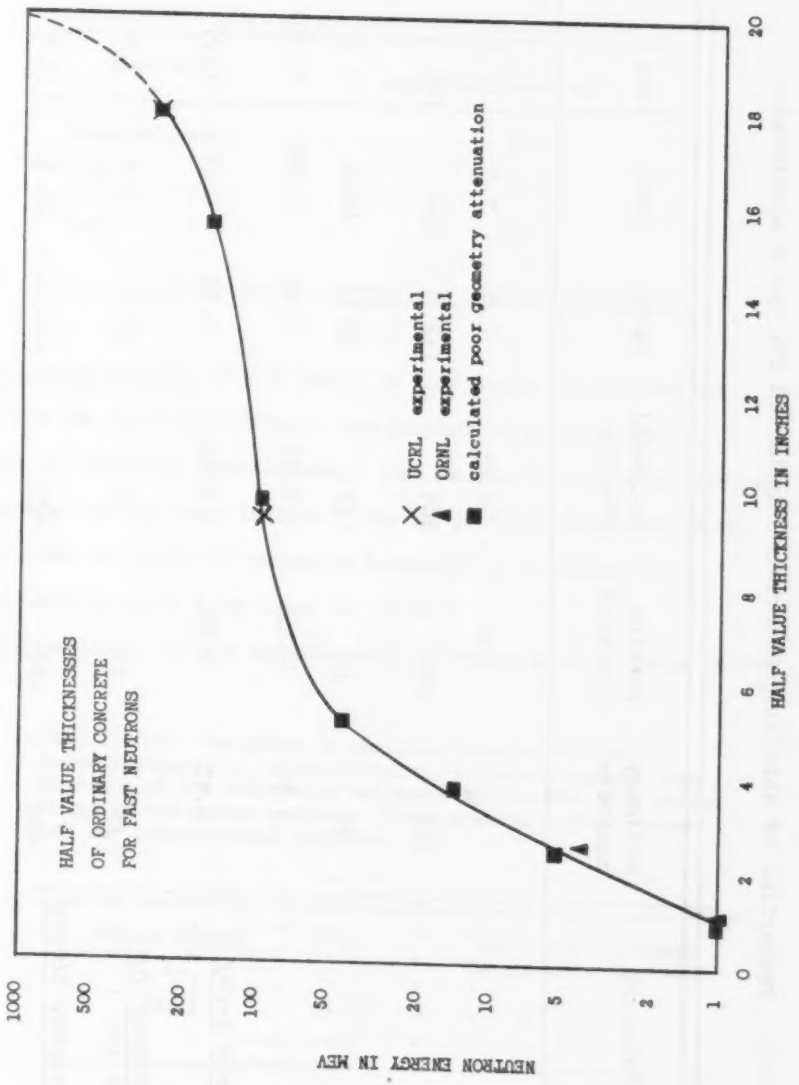
HALF VALUE THICKNESSES
OF ORDINARY CONCRETE
FOR FAST NEUTRONS
UCRL experimental
ORNL experimental
calculated poor geometry attenuation
NEUTRON ENERGY IN MEV
1000
500
200
100
50
20
10
5
2
1
0
2
4
6
8
10
12
14
16
18
20
HALF VALUE THICKNESS IN INCHES

FIG. II-C-1

TABLE II-C-1. Properties of shielding materials considered for the M accelerator

Property	Material	Ordinary concrete	Ferrite concrete	Fe-loaded concrete	Earth	Iron	Lead
Density:							
	g/cm^3	2.3	3.2	4.25	1.8	7.8	11.3
	lbs/ft^3	145	200	265	112	490	700
Radiation length:							
	g/cm^2	25	19	17	25	14.4	5.9
	ft	0.36	0.19	0.13	0.45	0.060	0.019
Mean free path at maximum γ-ray penetration (ft)		0.51	0.35	0.26	0.79	0.12	0.07
Neutron half-value thickness for neutrons of E > 1 Bev (in.)		20	14	11	26	7.2	7.9
Critical energy E_c for shower theory (Mev)		~50	~40	~35	~50	24.3	7.8

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TABLE II-C-2. Yield of neutrons per electron in various shielding materials for neutrons near the giant resonance.

Material	Y (neutrons/electron)
Concrete (earth)	34
Iron	25
Lead	18

2. High-Energy Neutrons ($E > 80$ Mev). In this region the neutrons are produced by the direct photoeffect. For purposes of calculations, we shall use an 'effective deuteron model,' i.e., assume that the cross section δ is the experimental cross section δ_D for the photodisintegration of the deuteron times an 'effective number of deuterons' in a nucleus (A,Z) which is experimentally about equal to 1.5 NZ/A.

Experimentally, we have approximately the values given in Table II-C-3.

TABLE II-C-3. Variation of the cross section for the photodisintegration of the deuteron with photon energy, and variation of the half-value thickness in concrete with photon energy in two energy regions. These are approximate values used for computational purposes.

Photon energy k (Mev)	δ_D (cm^2)	Half-value thickness in concrete (inches) $\lambda_{1/2}$
$80 < k < 300$	6×10^{-29}	$0.07\ k$
$k > 300$	$6 \times 10^{-24}/k^2$	20

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Hence, the neutron yield which has penetrated a shield of thickness t (in inches), ignoring obliquity effects, is

$$Y = \frac{N_0 X_0 NZE_0}{A^2} \left[\int_{80}^{300} \frac{6\times10^{-29}}{k^2} \exp\left(-\frac{t}{0.1\,k}\right) dk + \int_{300}^{\infty} \frac{6\times10^{-24}}{k^4} \exp\left(-\frac{t}{29}\right) dk \right] \quad (5)$$

$$= \frac{E_0 X_0 NZ}{A^2} \left[\frac{3.6\times10^{-6}}{t} \left(e^{-t/29} - e^{-t/8} \right) + 4.5\times10^{-8}\, e^{-t/29} \right] \quad (6)$$

$$= 1.0 \quad \frac{e^{-t/29} - e^{-t/8}}{t} + 0.013\, e^{-t/29}, \quad (7)$$

in ordinary concrete.

Equation (6) is of course quite approximate; in particular, the validity of δ_D to very high energies is doubtful. We are applying the neutron flux as calculated from Table II-C-2 and Eq. (6) for the consideration of transverse shielding. Actually, the high-energy neutron compone given by Eq. (6) are primarily directed forward. However, since we are considering shielding thicknesses that involve many mean free paths for elastic scattering also, we believe that the directionality of even the highest-energy components will not be too pronounced. The total flux of neutrons per incident electron is shown in Fig. II-C-2. Note that at shielding thicknesses in excess of approximately 7 ft of concrete, the highest-energy component becomes dominant.

3. Transverse Shielding Requirements. Let us consider the parameters and tolerances in 1.b and 1.d of this Appendix. At a distance of 10 meters the required attenuation is $(4\pi \times 10^{6} \times 3)/(2 \times 10^{13}) = 2 \times 10^{-6}$. We conclude from Fig. II-C-2 that we require a shield of 22 ft of ordinary concrete, or equivalent, as shown in Table II-C-4.

TABLE II-C-4. Summary of shielding requirements transverse to the beam of the M accelerator.

Material	Shielding thickness (ft)
Ordinary concrete	22
Earth	29
Ferrite concrete	15.5
Iron-loaded concrete	12
Iron	8
Lead	8.8

C. CALCULATIONS LEADING TO REQUIREMENTS FOR 'IN-LINE' SHIELDING

1. The 'Soft-Shower' Cascade. Let us consider the shielding requirements set by the radiation in the photon-electron shower. We will assume that the radiation is delivered in terms of minimum-ionization particles for which (1.b) we have set the tolerance to 7 electrons/cm^2 sec.

A shower is (very qualitatively) characterized by the fact that its spread in depth is a characteristic function of the radiation lengths penetrated until the mean energy is degenerated to the critical energy,

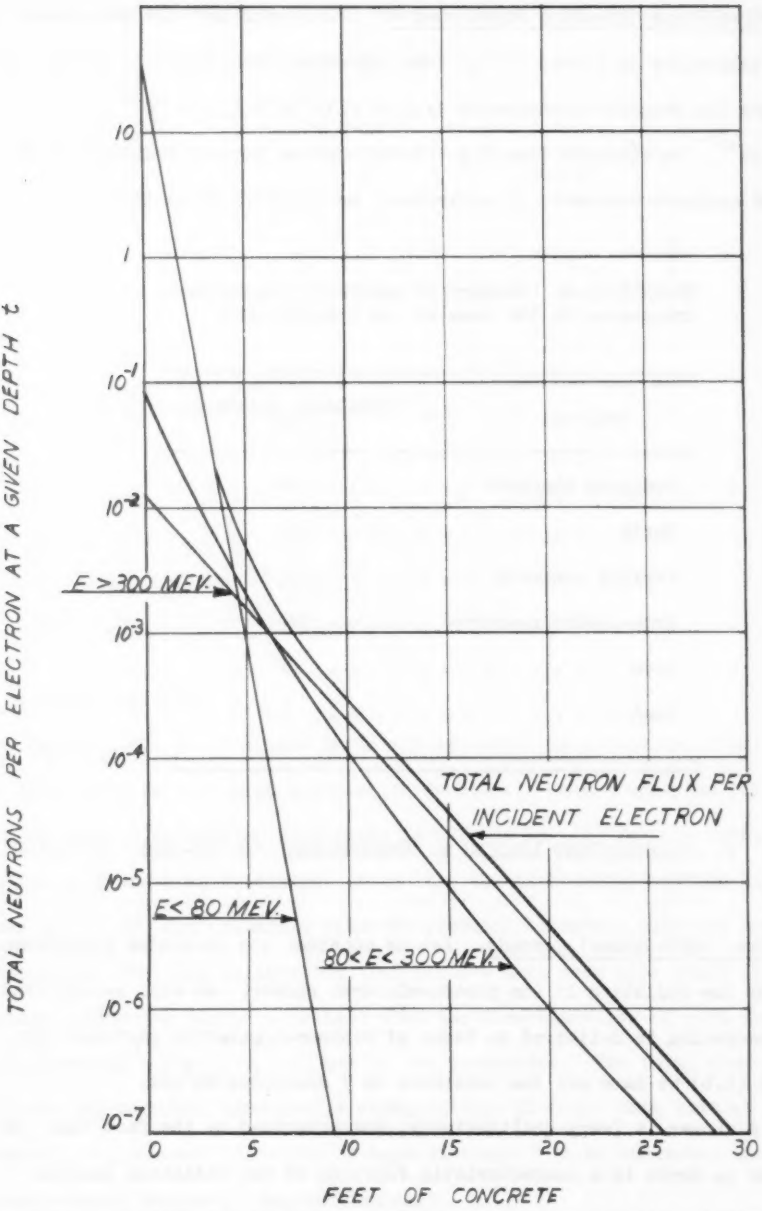

FIG. II-C-2. Total number of neutrons per incident electron 'surviving' at a depth t in concrete. Includes neutrons of all energies.

i.e., that energy at which the mean radiation and ionization loss of a charged particle are equal. Beyond that point we consider the shower absorbed by the absorption coefficient characteristic of the coefficient of γ-rays of maximum penetration (Table II-C-1). This crude model is satisfactory here since the large required attenuation demands a large part of the total course of the shower spent in its asymptotic form where the γ-ray absorption 'at minimum absorption' governs its behavior. From shower theory, we have the relations shown in Table II-C-5.

TABLE II-C-5. Shielding thickness required to degenerate electron-positron pairs originated by 45-Bev electrons to a value equal to the critical energy in the material.

Material	Distance to degenerate 45-Bev electrons to a mean value equal to the critical energy	
	Radiation lengths	Ft.
Concrete	12	4.2
Earth	12	5.4
Ferrite concrete	12	2.3
Iron-loaded concrete	13	1.7
Iron	14	0.85
Lead	18	0.35

In addition to the thicknesses shown in Table II-C-5, we must add the necessary factor to reduce the flux to tolerance at the maximum absorption coefficient for γ-rays. To arrive at the required attenuation, we have to estimate the lateral extent of the shower. At distances large compared to the shower maximum, the shower diameter becomes constant since

the secondary particles are being fed from the central core. It can be shown, both by simple arguments and also from experiment (A. Kantz, HEPL-17), that the radial extent of the 'terminal' shower measured in b/cm^2 (not radiation lengths) is remarkably constant; about half of the flux is contained within a radius of 50 g/cm^2. The required attenuation is thus given by the relation

$$(2.8 / p^2) \propto 10^{-9} \qquad (8)$$

where p is the density. As a result we obtain the quantities given in Table II-C-6.

We conclude that, in general, the radiation exposure due to the primary 'soft' shower is less serious than that of the accompanying neutrons.

2. The Nucleon Cascade. There exists no significant cosmic-ray information on the production of a nucleonic component by soft showers; rather, soft showers in cosmic rays are the products of events, via π^o production, which start from a nucleonic primary. Hence, estimate of the nucleon cascade induced by high-energy electromagnetic radiation rests on a very uncertain basis. We will assume here that the nucleon cascade commences from high-energy neutrons or protons produced by photodisintegration, and use the cross sections obtained by extrapolating the 'quasi-deuteron' model, as in the previous section.

According to Table II-C-3, we take the cross section for the high-energy nucleonic component to be $6 / k^2$ barns where k is the energy of the photon producing the 'quasi-deuteron.' This gives a yield

$$dY = 1.4(dk/k^3)$$

or

$$dY = 0.18(dE/E^3), \qquad (9)$$

TABLE II-C-6. Total shielding requirements to attenuate the 'soft'-component dose from 45-Bev electrons to tolerance.

Material:	Concrete	Earth	Ferrite concrete	Fe-loaded concrete	Iron	Lead
Required attenuation	5.4×10^{-10}	8.6×10^{-10}	2.6×10^{-10}	1.5×10^{-10}	0.46×10^{-10}	0.22×10^{-10}
Thickness beyond value shown in Table II-C-5 (in feet)	11.0	16.4	7.7	5.6	2.9	1.7
Thickness value from Table II-C-5 (in feet)	4.2	5.4	2.3	1.7	0.9	0.4
Total thickness	15.2 ft	21.9 ft	10.0 ft	7.3 ft	3.8 ft	2.1 ft

where E is the energy of the nucleon, and dY is the yield per incident electron corresponding to a nucleon in the energy band E to E + dE. We will use the curves of Messel[1] for the radial and depth distribution of the cascade.

The angular distribution for an energy degeneration of order 10^3 corresponds to a mean square angle 1.1 radian[2]. It also follows that the number of nucleons retaining more than 10^{-2} of their original energy falls to less than unity at a range of about 500 g/cm^2. Since the stopping power is essentially constant for nucleons of energy greater than ~ 100 Mev, we must add 500 g/cm^2 to the shielding thickness computed in 2.c, and also require a further attenuation of 4π due to the collimation of the shower into ~ 1 radian. We thus obtain values of required shielding in the forward direction given in Table II-C-7. These distances are considerably greater than the transverse requirements.

TABLE II-C-7. Shielding requirements in the forward direction as defined by nucleon cascades.

Material	Shielding thickness (ft)
Ordinary concrete	35.0
Earth	45.0
Ferrite concrete	24.9
Iron-loaded concrete	19.2
Iron	12.3
Lead	12.7

[1] H. Messel, in Progress in Cosmic Ray Physics, edited by J. G. Wilson (Inter-science Publishers, Inc., New York, 1954), Vol. II, pp. 135 ff.

3. μ-Mesons. The problem of shielding the muons produced in π-μ decays is quite serious. The main reason is that muons are stopped only by ionization instead of radiation processes or nuclear interaction. The pions that give rise to these muons will be produced in single- or multiple-photoproduction events (of the type originally discussed by Fermi), where the photons arise from electron-photon showers in the target or in the shield. These pions either undergo nuclear interactions or decay to muons; the first process is much more probable in condensed matter, but enough of the latter process remains to constitute a shielding problem.

In the discussion that follows, calculations based on the Fermi theory of multiple pion production are used.[1] This theory gives the relative probabilities of production of various numbers of pions as a function of photon energy. The over-all photopion cross section in the laboratory is taken to be

$$\delta(W_\gamma) = 2 \times 10^{-28} (300/W_\gamma)^s \, A \ \text{cm}^2, \tag{10}$$

where W_γ is the energy of the photon being absorbed, and A is the mass number of the bombarded nucleous. Equation (9) is suggested by the value of 2×10^{-28} cm^2 for pion photoproduction on hydrogen at 300 Mev. If s = 2, the cross section falls off less rapidly than the experimental data out to W_γ = 500 Mev; but for large photon energies s = 1 corresponds to $\delta \propto k^{-2}$, where k is the photon wave number in the center of mass. We must not expect that the cross section will fall off more rapidly than in proportion to k^{-2}, i.e., s = 1. The value s = 2 gives more favorable results but is probably not as realistic as s = 1.

The assumptions as to s and the theorectical pion multiplicity

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[1] R. H. Milburn, Revs. Modern Phys. 27, 1 (1955).

should be revised as soon as new experimental information becomes available nearer the energy range in which the proposed machine will operate.

We must calculate the laboratory energy of the pions before we can obtain an expression for the source of pions. We assume that the available c.m. energy is equally distributed among the pions; the laboratory energy is then obtained by a Lorentz transformation. We can now calculate the average number of pions $< n >_{Av}$ produced by a photon of energy W_γ in the laboratory which have energies greater than the energy W_1 of a muon that will just pass through the shield. The results of this calculation are given in Table II-C-8. The expressions shown are taken from a plot where a simple power law is assumed for the dependence on W_γ.

TABLE II-C-8. The number $< n >_{Av}$ of pions produced by a photon of energy W_γ in the laboratory of energy exceeding various energies W_1; mc^2 is the proton rest energy.

$< n >_{Av}$	W_1
$7.44 \times (W_\gamma / 50\ mc^2)^{1/2}$	4 Bev
$7.44 \times (W_\gamma / 50\ mc^2)$	7
$5.0 \times (W_\gamma / 50\ mc^2)$	10
$1.4 \times (W_\gamma / 50\ mc^2)$	14 Bev

To obtain the yield Y_π of pions per electron, we evaluate the track-length integral:

$$E_0 = 45 \text{ Bev}$$

$$Y_\pi = N_0 X_0 \int_{W_1} (0.57)(E_0/W_\gamma^2)\, \delta\,(W_\gamma) < n >_{Av} dW_\gamma, \quad (11)$$

where N_0 is Avogadro's number, E_0 is the primary electron energy (45 Bev), X_0 is the target radiation length in g/cm^2, $\delta(W_\gamma)$ is taken from Eq. (9), and $< n >_{Av}$ is taken from Table II-C-8.

We define the 'worst possible target' as the target thick enough to produce all these pions yet capture none. A good pion absorber, such as a heavy metal, should be located as close as possible behind the target in order to remove as many pions as possible through nuclear absorption. Any space between the target and the absorber leads to muon production through π-μ decays. The absorber should be at least 10 absorption-mean-free-paths long to reduce the pion flux to a value so that subsequent π-μ decays of remaining pions will not add appreciably to the muon flux. Furthermore, shielding material to stop the muons is cheap placed close to the target in comparison to what is necessary at a greater distance. In an actual end-station building, experiments will be set up at several points along the path of the beam. Hence a close heavy pion absorber must be moved every time a different experiment is done; this could prove inconvenient, and a detailed calculation of the economics involved is required to determine what percentage of the muon-stopping shield should be included in the absorber.

Let us assume that because of space requirements of instrumentation, it is possible to bring the pion absorber only as near as 3 ft to the target. To be conservative, let the target be the 'worst possible type,' and let its radiation length be 17 g/cm^2, which is in excess of the value for lead targets by a factor of about 3 and is very nearly the value for iron. The pion absorber shall be iron of thickness sufficient to reduce the muon flux to radiation workers' tolerance outside the shielding wall. In any case, the absorber shall be at least 10 nuclear-absorption mean-free-paths long, or $\sim$ 7.5 ft.

(11)

The number of pions produced in the target having energies greater than W_1 are given in Table II-C-9. Of those, Y_μ decay into muons in the space between the target and the absorber:

$$Y_\mu = Y_\mu \quad d(23.3 / E_\pi) , \qquad (12)$$

where d is the distance in meters between target and absorber, and E_π is the pion energy in Mev. These yields are also given in Table II-C-9. The total muon yield per second is given also for an electron beam current of 2×10^{13} electrons/sec.

TABLE II-C-9. Yields of π- and μ-mesons of energies greater than W_1. The incident electron energy is 45 Bev, and the beam consists of 2×10^{13} electrons/sec.

W_1	4 Bev	7 Bev	10 Bev	14 Bev
pions/electron:				
s = 1	1.3×10^{-3}	3.0×10^{-4}	1.3×10^{-4}	2.3×10^{-5}
s = 2	6.5×10^{-5}	7.5×10^{-6}	2.4×10^{-6}	3.6×10^{-7}
muons/electron:				
s = 1	7.4×10^{-6}	1.0×10^{-6}	3.0×10^{-7}	3.9×10^{-8}
s = 2	3.7×10^{-7}	2.5×10^{-8}	5.5×10^{-9}	6.1×10^{-10}
total muons/sec.				
s = 1	1.5×10^{8}	2.0×10^{7}	6.0×10^{6}	7.8×10^{5}
s = 2	7.5×10^{6}	5×10^{5}	1.1×10^{5}	1.2×10^{4}

The high-energy muons will mainly come out in a cone with a half-angle of 7° - 15°, depending on the energy. In caculating the flux, we

assume that they all come out in a 10° cone or within a solid angle of 0.096 sterad.

Let us assume that the back wall shield is 15-ft thick, of ferrite concrete with density 3.2, giving a surface density of 1460 g/cm^2. At each position of the target down the experimental area tunnel, the shielding necessary is different because of the changing solid angle factor. To carry out this calculation, it is necessary to interpolate between the values in the last row of Table II-C-9. It is a straightforward matter to compute the thicknesses of iron required in the absorber for various target positions (see Table II-C-10).

TABLE II-C-10. Iron required in addition to 15 ft of ferrite concrete (density 3.2) to reduce muon flux to tolerance.

Distance from target to 'safe side' of the shield	Thickness of iron required s = 1	s = 2
50 ft	39 ft	22 ft
75	35.4	19
100	33	17
150	30	14
200	27.5	12
250	25.4	10.7
300 ft	24 ft	9.4 ft

The iron required need not be fabricated in a complete cone, since the maximum angle at which mesons appear in the laboratory is a decreasing function of meson energy. An approximate calculation shows that a conical piece (A in Fig. II-C-3) with a 6-ft diam. base, plus several circular

iron wafers all of 6-ft diam. may be put together to form shields of the necessary thickness to satisfy the conditions of Table II-C-10. The conical shield A weighs 27 tons, and the total weight of the wafers B is 90 tons if s = 2 and 208 tons if s = 1. The iron cone is much more economical than the 110 ft of ferrite concrete that would be necessary to replace it. (These figures are for the case s = 2.)

4. Summary of 'In-Line' Shielding Requirements. As noted in the previous section, the problem of providing an adequate shield in line with the stopped beam of this accelerator is a very serious matter. The shielding requirements calculated for the various processes considered are quite dissimilar, and the most serious requirements are imposed by those processes where our ignorance concerning the needed quantitative data is highest. This fact, in combination with the as yet unspecified needs of particular experimental arrangements, calls for a maximum degree of flexibility in the 'end' walls of the target areas.

It appears advisable to use the values of Table II-C-7 as a minimum requirement. In the interest of maintaining the solid angle for experimental arrangements, iron or very-heavily-loaded concrete appears to be advisable. In addition, an arrangement similar to the μ-meson shield cone (3.c) will probably be necessary.

D. CONSIDERATIONS AFFECTING ROOF SHIELDING REQUIREMENTS IN TARGET AR

1. Air-Scattering Effect on Tolerance Directly Outside Shield. Detailed calculations concerning the air scattering of fast neutrons and other radiations have not been made as yet. From simple dimensional considerations, one can show that the ratio of the intensity I_D of 'direct' radiation to

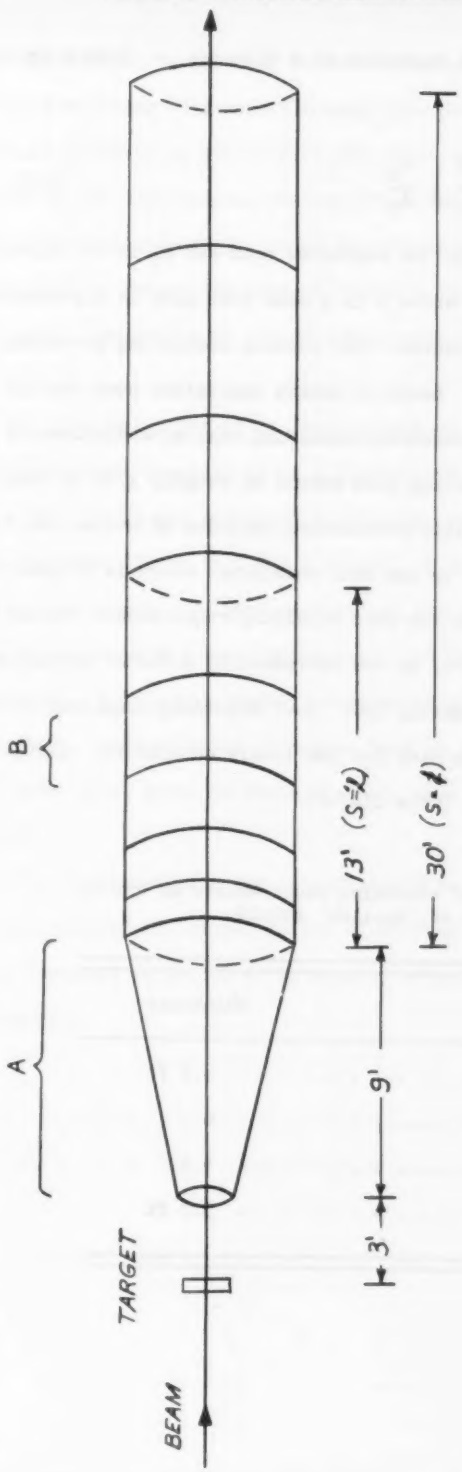

FIG. II-C-3. Shield consisting of a cone A joined by a cylinder to suppress μ-decay as much as practicable. The shield, preferably composed of iron or similar material, would have to be located along the forward radiation cone from each target.

the intensity I_S of scattered radiation at a distance r from a source is given by

$$\frac{I_S}{I_D} \simeq \left(\frac{r}{\lambda}\right) \frac{A_S}{A_D} , \qquad (13)$$

where A_S is the attenuation in the scattered path and A_D is the attenuation in the direct path, and where λ is a mean free path in air characteristic of the scattering process. For neutron scattering processes, λ is of the order of 1,000 ft; hence to obtain negligible contribution from air scattering outside the transverse shielding wall at a distance of 35 ft, the attenuation in the scattering path should be roughly 1/30 of that required in the direct path. This attenuation includes of course the fractional solid angle subtended by the roof shielding, which is in general only about 10 percent. Hence the roof shielding requirements correspond to those given in Table II-C-4, by are decreased by a factor corresponding to an attenuation of approximately 300. Roof shielding requirements from this point of view (i.e., the need for low levels outside the 'direct' shield) are thus as given in Table II-C-11.

TABLE II-C-11. Roof shielding requirements as set by tolerance near base of 'in-line' shield.

Material	Thickness
Ordinary concrete	8.5 ft
Ferrite concrete	6
Fe-loaded concrete	4.5
Iron	3.3 ft

This calculation is probably somewhat conservative since the nonisotropy of the scattering will make the mean free path for back scattering of neutrons probably in excess of 1,000 ft as assumed above. This is documented by the experimental finding (from the 184-in. cyclotron, UCRL) that a roof shield of one fourth the thickness of the side shield is sufficient to reduce the neutron fluxes as produced by air scattering to a value comparable to the directly penetrating component.

2. Air Scattering Effect on Regions Outside Project Boundaries. The nearest project boundary is at a distance of roughly 500 ft from the target area. It is our intention to hold the permissible radiation levels outside these limits to 0.002 r / week, or 1/60 of the design dose for project personnel. We have carried out air-scattering calculations based on the following two basic processes: (a) neutron diffraction scattering on nuclei; (b) 'quasi-elastic' scattering of neutrons on nucleons within a nucleus. Both of these processes lead to roof shielding requirements less than those given in Table II-C-11, even considering the lowered tolerance.

The inverse-square law is sufficient to reduce the direct radiation by the required additional factor of 60 from the outside of the shielding walls (assumed in Sec. B as 10 meters) to points outside the project boundaries.

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APPENDIX IV-A

Summary of Control and Instrumentation Specifications

A. GENERAL PROVISIONS

Tentative specifications on instrumentation and control are given in this section by first briefly describing the accelerator lay-out and then specifying the instrumentation and control circuitry to be used.

Most of the specifications given here are dictated by the general machine and klystron specifications described in Section IV and Appendix IV-B. The remainder are based on operating experience obtained with the existing Stanford accelerators.

As previously stated, the accelerator will be housed in a tunnel nominally 10,000 feet long. At the end of the accelerator proper the electron beam will be magnetically extracted and distributed into various areas of the 'end station' for experimental studies. This is described in detail in Section IV, and as such nothing further will be stated about the problem here. Parallel to the accelerator tunnel is another structure, the 'klystron tunnel', which will house the klystrons, the klystron modulators, the vacuum pumps, the control equipment, and other auxiliary equipment necessary for operation of the accelerator. It is the instrumentation and control of all of the equipment in these two tunnels with which this Appendix is primarily concerned. The discussion that follows describes the equipment in these tunnels and states briefly the nature of the controls that will be necessary.

The control and instrumentation specifications of an accelerator

are determined not only by the performance specifications of the machine, but also by the procedures adopted for maintenance, tune-up, and routine operation. Therefore, before listing the instrumentation specifications, it is necessary to review their requirements from a procedural viewpoint:

1. The first important consideration is that the accelerator tunnel will be uninhabitable while the machine is operating. All equipment that may need frequent servicing should therefore be located in a more accessible area, namely, the klystron tunnel. Whatever equipment is located in the accelerator tunnel must be built and installed in a manner that will allow rapid servicing or replacement in order to minimize the time during which the accelerator is inoperative.

2. Since the accelerator is scheduled to operate 24 hours per day, routine maintenance must be accomplished without interfering with operation. Examples of such routine maintenance are the replacement of klystrons; servicing of spark gaps, vacuum pumps, DC power supplies; tuning up the accelerator, i.e., adjusting r-f synchronization and power level of the various sections; etc. These operations can easily be accomplished if the accelerator is divided into a relatively large number of 'sectors' (say 40), such that during normal operation the performance of the accelerator will still be satisfactory with one or two of these sectors turned off.

For tune-up purposes, the sector can be operated as an independent accelerator with its own gun and beam extraction system. This appears to be feasible if the sectors have pulsed injection and extraction systems operating at a low repetition rate, and if the pulse occurs a few microseconds after the normal accelerator pulse. Tuning of each sector of the accelerator will be performed at a console located near one end of

each sector.[1]

In order to facilitate the servicing of large numbers of identical units (from 40 to 920 each of various components) it is proposed that, with the exception of certain routine adjustments such as tuning accelerator sectors or lubricating motors, all servicing shall consist of replacement of entire units or major parts of units. (These replaceable units are described below.) To make the replacement of large units more convenient, it will be desirable, although not essential, that the arrangement of equipment and access space be identical for each 250-foot sector. Trouble-shooting and repair of extracted units will be performed by technicians in a shop area outside the tunnel.

It is expected that all of the equipment that must be located in the accelerator tunnel may be so designed that it will not require servicing more often than once in six months. In the klystron tunnel the equipment should not require servicing more than once a week. It is also expected that the failure of a klystron or a modulator unit may be ignored until the next regular servicing period.

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[1]Accurate phasing becomes increasingly difficult as the number of independent 10-foot sections being tuned increases. Experience has shown that it would be difficult to obtain the phasing accuracy required with more than 25 10-foot sections in a sector. Hence, it is planned that each sector be tuned independently and that the sector be composed of 23 10-foot sections, an electron gun, a beam inflecting system, a magnetic extraction system, plus beam detection equipment; the total sector occupying a length of 250 feet.

Continuous servicing will be provided by two crews of technicians capable of servicing four 250-foot sectors per 8-hour shift. This will probably constitute 8 - 10 men per shift. These crews would, on a regular schedule, service the accelerator equipment. An additional crew of between 6 and 12 men would have to be available in case of a major breakdown of an entire 250-foot sector, e.g., vacuum pumps, DC supply, etc. Such units would have to be serviced without delay.

It is anticipated that during initial installation and test of the accelerator, and during periods of major overhaul, as many as 100 people and 30 vehicles, trailers, or other mobile pieces of equipment, are likely to occupy the klystron tunnel at one time.

The main control area will have instrumentation for controlling the 40 sectors as integral units only. They will be controlled in a manner analogous to the control of individual 10-foot sections within a 250-foot sector. The main control area will also have rudimentary monitors for checking performance of each klystron or of other replaceable units and a switch for turning each unit on or off. More detailed monitoring will exist only at the 250-foot consoles in the klystron tunnel. Provision will be made, however, for complete remote control and monitoring of the vacuum systems. No provision for multiplexing of information or control channels has been considered in this Proposal. Such equipment might, however, considerably reduce the wiring costs of the machine and/or provide more information at the main control panel. An important problem, however, will be to keep the control panel from being too complex or cumbersome to operate.

3. Auxiliary Equipment. By means of appropriate vacuum valves in the manifold in the accelerator tunnel, it will be possible to isolate the vacuum system of each 250-foot sector from that of adjacent sectors. The manifold for each sector will have its own pumping station located in the klystron tunnel. Provision will be made for pumping any manifold from the manifold of an adjacent sector when required. Connections for optional use of leak detectors and ion gauges (or other high-vacuum gauges) will be installed at each 10-foot pumping connection to the accelerator. The power supplies for these gauges will be located at the corresponding klystron modulator units. Steering, focusing, and degaussing coils will be provided for each 250-foot sector. A non-intercepting beam current monitor will be placed after Section 23 in each sector.

4. Maintenance and Access. Every 10 feet there will be a lateral feed between tunnels containing a waveguide and appropriate control and signal wires. At the middle of every 250-foot sector there will be a lateral tunnel for personnel access, which will also contain a vacuum line pumping the accelerator manifold. Access for equipment will be provided at a point near each end of the lateral tunnel. It must be possible to replace any piece of equipment without major displacement of adjacent equipment. All parts within the accelerator must be easily accessible. Provision must be made for hoisting and transporting units weighing up to 1 ton. The accelerator tunnel obviously may be entered only when the accelerator is not operating. Although the accelerator tunnel will be entered only when absolutely necessary, the tunnel may have to be occupied by as many as 30 people during such periods.

B. THE ACCELERATOR TUNNEL

1. Description. The accelerator will be a 4-inch diameter copper waveguide made in 10-foot sections. The axis of the pipe must lie within 1/16 inch of a straight line over short distances, and within one inch over the entire length of the accelerator. Equipment to set and maintain the alignment may have to be installed in the tunnel. The pipe will be evacuated to a pressure lower than 5×10^{-6} mm of Hg by means of vacuum-pumping connections every 10 feet. R-f power, ranging from zero to 2.5 kw average, is fed into each 10-foot section by a waveguide from the klystron tunnel. The temperature of each 250-foot sector must be held constant to within 2° C of a prescribed temperature by means of a water-cooling jacket. This prescribed temperature may have to be determined experimentally for each 250-foot sector but will lie within a 10° range.

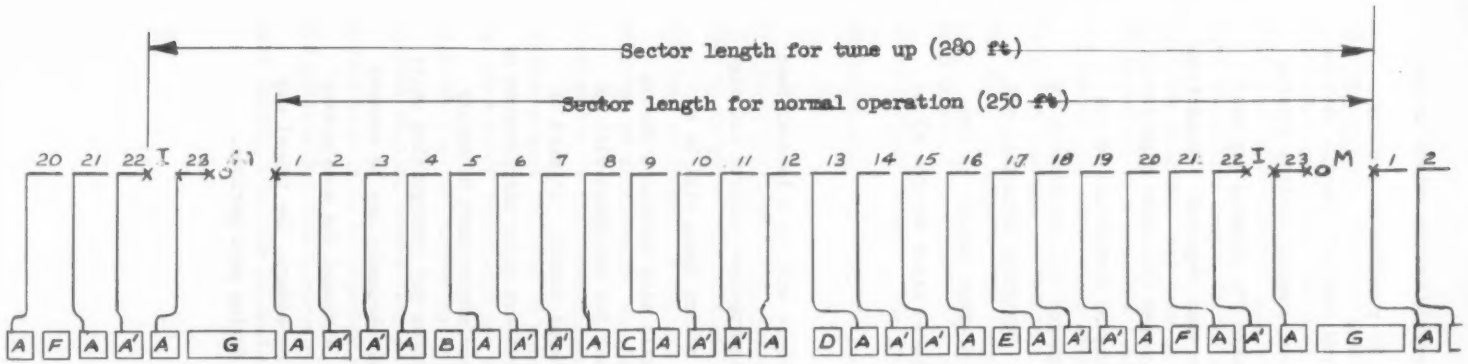
2. Subdivision of the Accelerator into Sectors. For operational and tune-up purposes, the accelerator will be organized in sectors nominally 250 feet in length. A typical sector will be composed of 22 10-foot sections of accelerator, an electron injector, a 10-foot section of accelerator, a non-intercepting beam current monitor, and a pulsed analyzing magnet followed by a beam collector (see Fig. IV-A-1.) For tuning up, an electron source and the following 10-foot section serves as an injector for the succeeding 23 sections and deflection magnet. The 10-foot section between the gun and magnet as shown in Fig. 1 is used during tune-up as an injector for the following 23 sections, with special r-f phasing for this purpose. It is normally adjusted to operate as the last section with the proceeding 22 sections.

C. THE KLYSTRON TUNNEL

1. General. In addition to the klystrons, the klystron tunnel contains nearly all of the equipment powering and serving the accelerator: vacuum-pumping stations, klystron modulators, tuning consoles, DC power supplies, r-f and trigger-signal feedlines and their booster supplies, tuning consoles, and all control and signal circuitry. In numbers, these units range from 40 to 920 identical units of a type. Primary access to the klystron tunnel for equipment and other bulky objects will be from a point adjacent to the repair shop and from a point adjacent to the control area. The radiation from the accelerator and the klystrons must not exceed a level which would make the tunnel safe for continuous occupancy.

2. Cross-Section Layout. Several cross-section layouts of the klystron tunnel are possible, as shown in Figs. IV-A-2 and 3. They differ primarily in the arrangement of space allowed for transportation of equipment and space for wiring. The layout shown in Fig. IV-A-2 is the preferred arrangement for the tunnel in this Proposal. In each layout, a line of klystron modulators and other units of equipment is placed near one wall. Between the equipment and the wall is manifolding for vacuum, air and water. The manifolds will be in 40-foot sections and will be accessible for replacement or repair when the five equipment units which they serve are removed. On the other side of the equipment is space for two-way traffic transporting personnel and equipment along the tunnel. Between the equipment and the traffic area is a pedestrian walk for people working on the equipment. All longitudinal wiring is carried overhead on an upper deck with generous access space. The upper deck is to be so supported

Fig. IV-A-1. Schematic layout of equipment in accelerator and klystron tunnels for one sector of machine.


Sector length for tune up (280 ft)
Sector length for normal operation (250 ft)
20 21 22 I 23 o 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 I 23 o M 1 2
A F A A' A G A A' A' A B A A' A' A C A A' A' A D A A' A' A E A A' A' A F A A' A G A

A Klystron modulator, Stage I and II

A' Klystron modulator, Stage II only

B Booster unit (Amplifier for r-f drive and trigger signals)

C Auxiliary supplies for focus, steering, etc.

D Pumping Unit

E Storage space

F Control console

G DC power supply

× vacuum isolation valves

o non-intercepting beam monitor

I injector

M deflection magnet

Fig. IV-A-1. Schematic layout of equipment in accelerator and klystron tunnels for one sector of machine.

1. [illegible] deck [illegible] on t [illegible] the [illegible] traf [illegible] are [illegible] for [illegible] wat [illegible] Bet [illegible] Kly [illegible] arr [illegible] spe [illegible] in [illegible] tum

2. [illegible] whi [illegible] rad [illegible] to [illegible] tum [illegible] fro [illegible] and [illegible] r- [illegible] pul [illegible] ne [illegible]

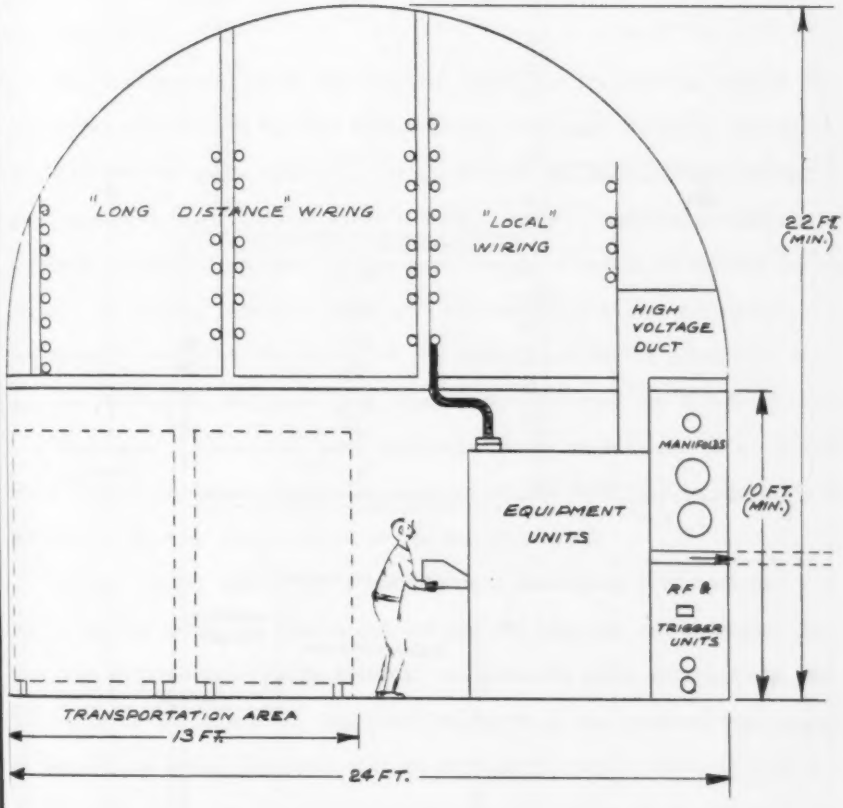


Fig. IV-A-2. Cross section of klystron tunnel.

that, when the equipment units are removed, a 40-foot section of manifold may easily be moved from the manifold area to the transportation area.

3. Longitudinal Layout. The 40 operational sectors of the accelerator are laid out exactly the same. The layout of a 250-foot sector is shown in Fig. IV-A-1. Space is allowed for 23 klystron modulators for Stage II operation, although only 12 modulators would be installed for Stage I. With the exception of the DC supplies, each unit of equipment will occupy a space not exceeding five feet along the tunnel, six feet across the tunnel and a maximum of eight feet in height. The DC supply will occupy a space about 20 feet long, 6 feet wide and 8 feet high. The units are placed nominally every 8 feet along the tunnel so that there is space for an auxiliary unit between each group of four modulators. Because of the personnel access tunnel at the center of the sector, the units are displaced from the center of the sector outwards, as indicated in the figure.

D. MAJOR EQUIPMENT UNITS IN THE KLYSTRON TUNNEL

All of the major equipment units in the klystron tunnel are to be built so that they may be lifted or rolled into position. As much as possible, all connections will 'plug in' when the equipment is placed in position. All of the equipment will have the same general framework so that it can be moved in the same fashion; only the DC supply is a different shape, but this could be built in four sections, 5 x 6 x 8 feet, the same as the other units. The letters preceding the descriptions below correspond to the designations in Fig. IV-A-1.

A. Klystron Modulators, Stage I. The klystron modulators are

described elsewhere in this report. Their function is to deliver DC high voltage to the cathodes of the klystrons. Input to these modulators includes 15 kv DC from the DC supplies, AC power for certain auxiliary components, an r-f drive signal, a trigger signal, and certain other control signals. Cooling water and air for the spark gaps are also required.

The instrumentation of the klystron modulator involves mechanical and electrical disconnects for the high voltage, a trigger amplifier and gating circuit, two ion gauge amplifiers which control the gate circuit, an r-f power meter, a circuit which gives a single 'off-on' indication that the klystron is delivering power to the accelerator, a rectifier for the focusing coils, and various safety interlocks. Associated with each modulator, but mounted in the manifold area of the tunnel, are an r-f attenuator and a phase shifter in the input feed line, controlled from the 250-foot console.

For Stage I operation, each modulator feeds two sections of accelerator, and a high-power phase shifter is required in the feed line to one of these sections. This is also mounted in the manifold area.

Normal weekly servicing of the klystron modulators will include replacing the spark gap switch and testing the klystron and modulator for possible malfunction. Malfunction of the klystron alone will dictate replacement of the klystron. Any other malfunction will require replacement of the entire unit. The unit will be self-protecting so that, if a part of the unit fails, no damage will occur to other parts of the unit if the fault is ignored until the next regular servicing period.

A'. Klystron Modulators, Stage II. In Stage II, every modulator position is filled, every modulator has a phase shifter in its input feed, and the high-power phase shifter in the output waveguide is no longer required. Otherwise the modulators are the same as before.

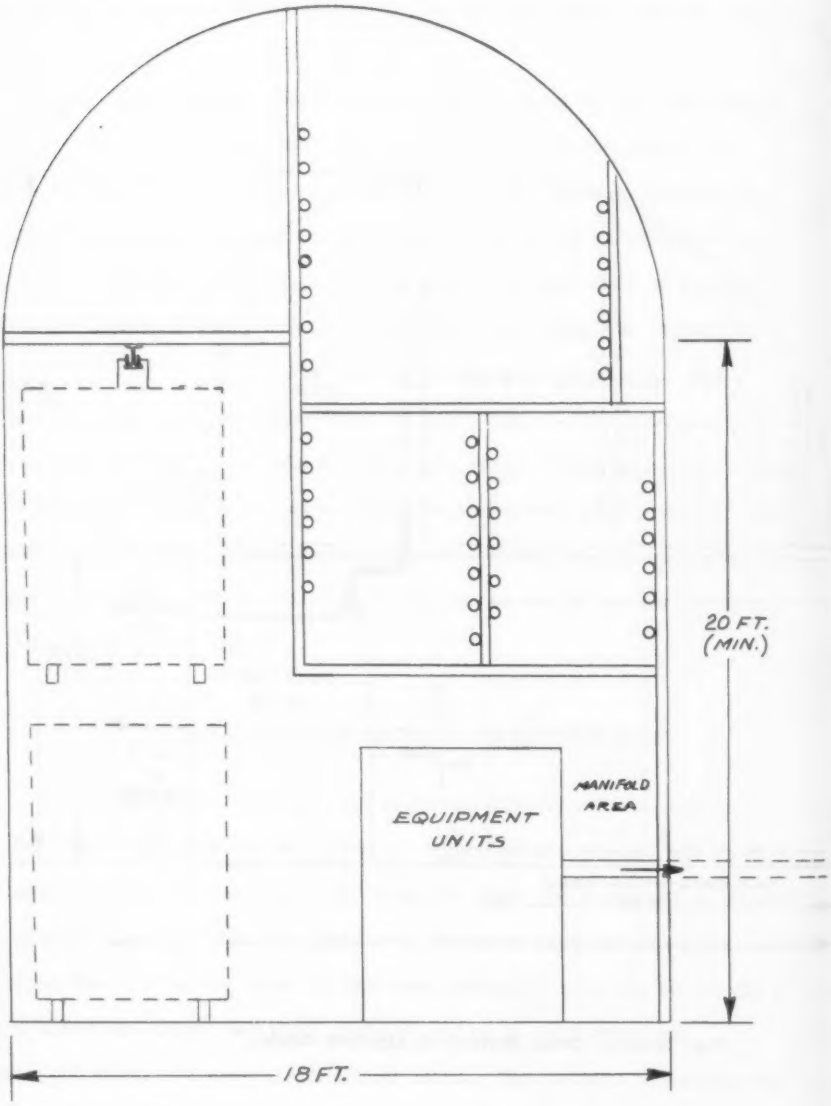


Fig. IV-A-3. Alternate cross section of klystron tunnel.

B. Booster Unit. Each sector of the accelerator has an r-f booster klystron which samples power in the master r-f feed line which runs the length of the accelerator. The booster delivers approximately 1 Mw to a sector feed line which supplies r-f power to each klystron modulator. Its instrumentation is similar to that of the klystron modulator with the exception of the ion gauge amplifiers. It also has a phase shifter associated with it, which is controlled from the main control area of the entire accelerator.

The booster unit also contains an amplifier for the trigger signal. This unit samples the signal in the master trigger line and delivers power to a sector trigger line. It also has provision for delaying the trigger approximately 100 microseconds for tuning purposes.

Three extra booster units are required, one every 2,500 feet, in the master r-f feed line.

C. Auxiliary Supplies. Space must be allowed for certain auxiliary supplies such as focusing and steering supplies for the accelerator, and possibly power supplies for the electron injector and the deflection magnet. Part of this space may be used for storage of spare parts or for such telemetering equipment as may prove desirable at a later date.

D. Pumping Unit. Each sector will have two high-vacuum pumps and a roughing pump which will be connected by appropriate solenoid valves to the accelerator manifold and a manifold for pumping the output waveguides (Details to follow). Appropriate vacuum gauges at each pump and manifold will close valves automatically in the event of vacuum trouble. The gauges and valves will also be connected to the main control area. Provision will also be made to have either high-vacuum pump handle both manifolds simultaneously, thus permitting one pump to be serviced without interfering with the operation of the accelerator.

E. Storage Space. Although there will be many empty spaces in the line of equipment units during Stage I operation, it is essential to reserve some space for storage and other uses when operation reaches the Stage II level.

F. Control Consoles. The 250-foot console will be a simplified version of the console now used for the Stanford Mark III accelerator. It will contain all instrumentation required to obtain maximum energy from a 250-foot sector, and will contain sufficient indicators to locate any source of trouble within the sector.

It should be noted that modulator No. 23 of each sector may come under the control of either the preceding or the following console during tuning. Its normal operation is with the preceding sections, but a special connection to the r-f and trigger lines of the following section must be made when that section is to be tuned. This special connection may be controlled at the 250-foot console.

G. DC Supply. The DC supply unit will contain not only the 15 kv DC supply, but also transformers and a distribution panel for supplying AC power to the equipment in each sector. The unit may be built in sections that are easily disconnected for servicing. Details of the DC supply and the power distribution equipment are specified elsewhere in this Proposal.

H. Mobile Equipment. In addition to the fixed units in the tunnel, it will be necessary to have some special equipment on mobile carts. For example, the power supplies for the sector deflection magnets will normally be used only once a week at any given sector. Hence, two or three such mobile supplies might adequately serve the entire accelerator. Certain specialized pieces of test equipment may also be mobilized in order to reduce duplication of equipment which is infrequently used. Special carriers may be used for transporting equipment units in and out of the tunnel.

It is largely to allow traffic to pass such units when they are necessarily stopped at some point that the tunnel must provide room for two-way traffic at all points.

E. VACUUM SYSTEM

The pumping units described above must evacuate three manifolds, a 20" accelerator manifold, a 10" waveguide manifold, and a 6" roughing manifold. The accelerator manifold is connected to the accelerator at each input feed. An ion gauge and a valve allowing the connection of a leak detector are also located at each waveguide feed. In the accelerator manifold and along the accelerator itself are valves which serve to divide the vacuum system into 250-foot sections, and which may isolate the electron inflection and deflection systems from the main accelerator vacuum if servicing is required. The waveguide manifold evacuates a short section of waveguide between the output window of the klystron itself and another vacuum window. When a klystron is replaced, only this short section of waveguide must be let down to air. Each such section of waveguide has its own ion gauge, a valve to the accelerator manifold, a valve to the roughing system, and a let-down valve. During Stage I operation, the high-power phase shifter is located in this section of waveguide. There is no need for remote control of those valves, but all other valves should be controlled both at the appropriate pumping station and at the main control area. The ion gauges at each station control the trigger gate at the nearest klystron modulator and may be monitored at the appropriate 250-foot console.

F. MAIN CONTROL AREA

The main control area shall have complete monitoring and control panels for substations, DC supplies and generators, water system, and vacuum system. Operating controls for the accelerator, however, shall be reduced to a minimum. There must be a board of some 1,200 lights to indicate performance or non-performance of each of the major equipment units in the klystron tunnel. There must also be an on-off control for each unit. The operator must have signals from the non-intercepting beam monitors at each sector and from beam monitors in the end station. He must have control of the r-f phase shifter, the steering and focusing circuits, and the DC supply voltage for each sector. He must also be able to control the main beam-deflection magnets. He must be able to delegate energy control and main on-off control of the beam to the experimenters.

In addition, the main control area must have a communication system to connect it with the experimental areas and with each maintenance crew wherever they may be located in either tunnel. This will include closed circuits and a public-address system. It will also include a closed-circuit television system which has provision for pickup units to be located at various points in either tunnel should the need arise.

The control area will also have control and monitoring of the master trigger generator, the master microwave oscillator, the radiation monitoring system, and the radiation interlock protection system.

G. WIRING

The primary expense of the instrumentation of the accelerator is the wiring and the upper deck required to contain it. It has been assumed

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that two wires are used for each signal, for each control function, etc. Coaxial cables will be used for the master trigger line, the master r-f line, and for a few circuits within each 250-foot sector. The wiring will be installed in multi-conductor cables to as great an extent as possible. Near the main control area, these cables will line the walls of three corridors (six walls) to a height of about six feet. These corridors must be six feet wide to allow convenient installation or replacement of cables. This space will handle all control and signal cables and most, if not all, power lines.

It is entirely possible that suitable multiplexing equipment would substantially reduce the wiring and allow a much lighter or smaller deck to be built to support the wiring. It is also possible that this would result in a less reliable system. No estimate of the possible saving is now available.

H. ENGINEERING PROBLEMS

The instrumentation described here is entirely conservative with two exceptions:

1) It is not now certain that all of the equipment can be made entirely self protecting so that in case of failure it may indeed be ignored until the next servicing period.

2) The engineering details of a pulsed injection and deflection system have not been worked out in detail.

The self-protection is a straight-forward problem which is solved regularly in industrial situations. It should offer no serious difficulties. The pulsed inflector is also straightforward. The pulsed deflection system is possible in principle: the beam is directed between

the center and outer conductors of a curved coaxial line which carries a very large current. The power required for such a device is of the order of 10 to 20 kilowatts for repetition rates of two to four pulses per second. So far, however, only a feasibility study of this system has been completed.

The remainder of the instrumentation is straightforward and is based directly on circuits and operational procedures now in use on the Stanford Mark III accelerator.

APPENDIX IV-B

Klystron Requirements and Specifications

A. INTRODUCTION

The kind, number and characteristics of the klystrons needed for this project are described in this section, together with a description of the facility needed to produce these tubes. The requirements for the klystrons and the fabrication facility for both Stage I and Stage II are given.

For Stage I operation the accelerator will require 480 klystron amplifiers, each delivering 2 microsecond pulses at 6 megawatts peak power at 360 pulses per second. The peak power of the present 30 megawatt Stanford klystrons has been derated to the above level to provide a margin of safety in the performance and life. The proposed tubes will be nearly identical to those presently used on the Stanford Mark III and Mark IV accelerators and are expected to provide a useful lifetime of at least 2,000 hours under these moderate operating conditions. The tubes presently used are considered as a 'prototype' in this study.[1] Mechanical redesign of these tubes will be necessary to simplify production problems and to allow rapid interchange of the tubes in use. As operating experience with the tubes permits improvement in their characteristics, it is expected that the klystrons can be operated at higher power levels consistent with

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[1] For a description of the present tube structures see Chodorow, Ginzton, Neilsen, and Sonkin, I.R.E. 41, 1584 (1953), or Chodorow, et. al., R.S.I, 26, 134 (1955).

a tube lifetime equal to or exceeding 2,000 hours until the final goal of 22 megawatts at 60 pulses per second is attained.[1] When this performance is attained, the number of tubes supplying power to the accelerator will be increased to 920. This power level of operation and the number of klystrons defines the attainment of Stage II.

Because of the large number of tubes required, initially and during operation, it is necessary to build a special 'factory' for the specific purpose for manufacturing and repairing these tubes. It should be noted that although similar klystrons are now in commercial production, the largest known rate of production is approximately 50 tubes per month. It is believed that a factory closely integrated with the needs of the accelerator will result in lower costs and better service to the project. A flow of tubes, fluctuating in number due to the particular needs of the accelerator, needs to be assured at all times. It is expected that the klystron factory will be located on the accelerator site and will be managed as a part of the proposed accelerator project. It is possible, however, that the klystron factory can be operated by some commercial organization rather than under the direct management of the Stanford accelerator project; the choice between the two methods of operation and the exact location of the site for the klystron factory will be reviewed at an appropriate time. At least one commerical firm has expressed a serious interest in manufacturing the klystrons for this project and cost estimates for the various stages of production of klystrons have been supplied to us by Varian Associates.

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[1] This is the present operating level of the continuously pumped tubes used on the existing Stanford accelerators.

Fig. IV-B-1 shows a block diagram of the microwave radio frequency system for supplying power to the accelerator during Stage I operation.

B. THE KLYSTRON FACTORY

Two alternative procedures have been considered in estimating the klystron factory requirements:

Alternate One is to install initially a facility sufficiently large to produce and maintain tubes for Stage I operation on a one shift per day basis. A slight increase in the size of this facility and a two shift per day schedule would then supply and maintain the tubes required for Stage II operation. This alternate has the advantage of providing a transition from Stage I to Stage II operation with minimum disruption of the original facilities. Furthermore, it provides the necessary flexibility to increase production for short periods during Stage I should the need arise.

Alternate Two is to provide a smaller initial facility based on a two shift per day schedule for Stage I operation, and then increase the size of the factory by about 40 percent for Stage II operation.

Although the second alternative has the lower initial cost, the ultimate cost would be higher. Furthermore, it would tend to jeopardize the operation of the accelerator during the factory transition period and would also reduce the flexibility of the plant during the initial operational period. The descriptions that follow in this section and the cost estimates of Section V are predicated on alternate number one.

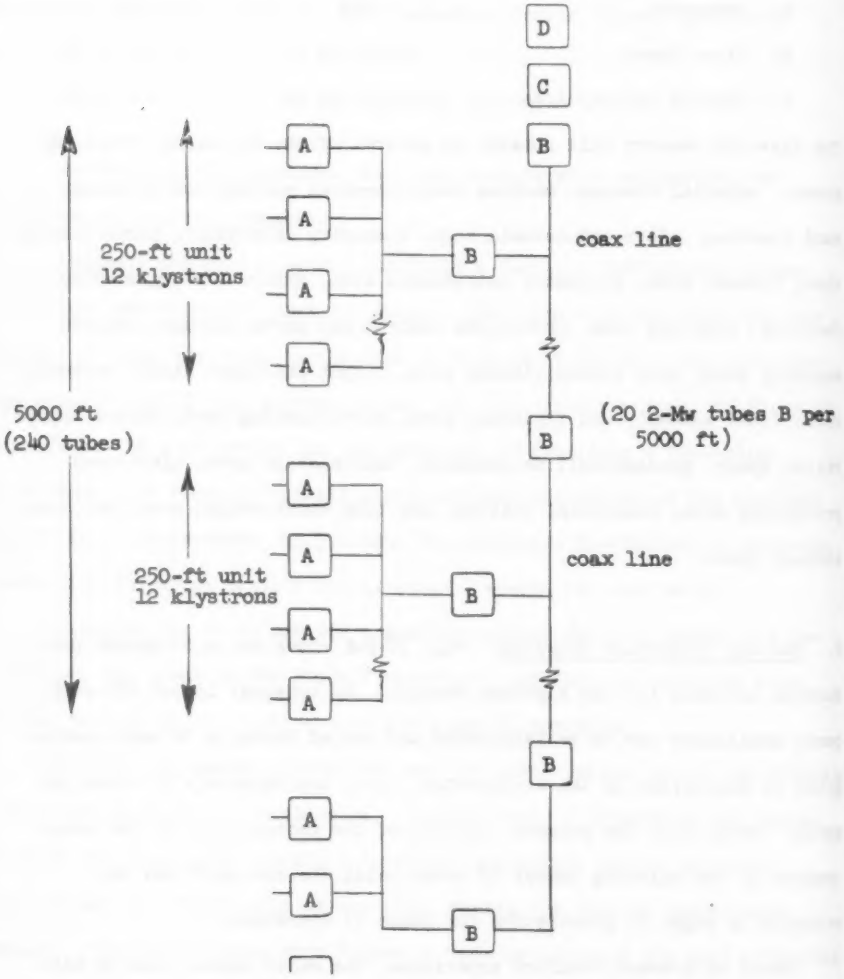
1. The Klystron Factory Specifications. The estimated size of the klystron factory is:

	Stage I	Stage II
a) Personnel	110	180
b) Floor Space	24,000 sq ft	25,500 sq ft
c) Outside Utility Area	6,000 sq ft	6,000 sq ft

The klystron factory will consist in general of the following functional areas: material storage, machine shop, chemical plating and cleaning, sand blasting, glass and ceramic shop, chemistry laboratory, parts inspection, furnace room, equipment maintenance shop, production engineering facility, drafting room, production control and parts storage, cathode assembly area, body reconditioning area, output and input window assembly area, final assembly and finishing area, torch brazing area, direct supervision space, package-unit maintenance, bake-station area, electrical processing area, electrical testing, new tube construction area, and tube storage space.

2. Factory Production Schedule. Fig. IV-B-2 shows the anticipated production schedule for the klystron factory. An original lot of 630 main power amplifiers are to be fabricated and tested during a 22 month period prior to completion of the accelerator, i.e., approximately 35 tubes per month. After this the primary function of the factory will be the maintenance of the existing number of tubes until the two shift per day schedule is begun in preparation for Stage II operation.

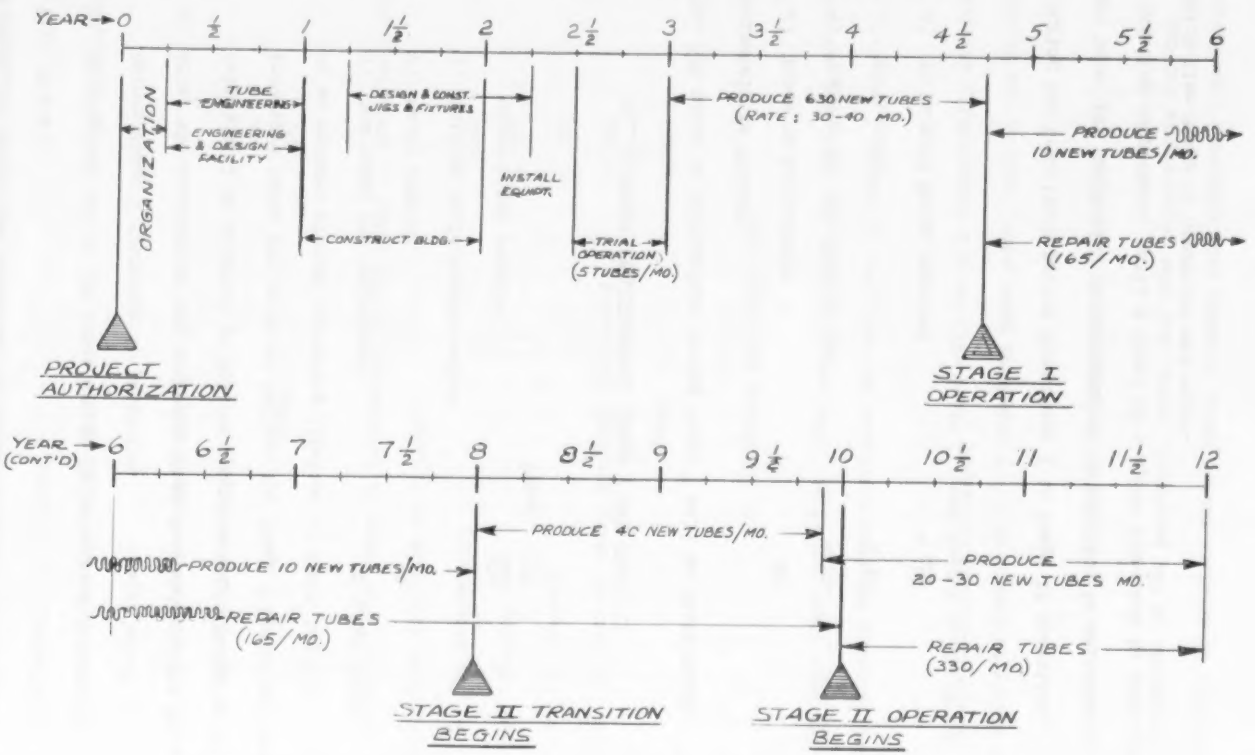
Based on present Stanford experience, the major repair item of klystrons is the replacement of the oxide emitting surface of the cathode. However, a small percentage of used tubes require more estensive reconditioning; these shall be classed as 'major repairs' in the following tables. Occasionally, it is less expensive to build an entirely new structure than to undertake a major repair. Therefore, on the basis of present



LEGEND:	Symbol	Tube	Quantity
	A	6-Mw klystron	480
	B	2-Mw klystron	40
	C	50-w klystron	1
	D	Crystal master oscillator	1

Fig. IV-B-1. Klystron chain block diagram for Stage I operation.

Fig. IV-B-2



PRODUCTION SCHEDULE – POWER AMPLIFIER KLYSTRON

experience, the production schedule for Project M is as follows (see also Fig. IV-B-2).

a) An original lot of 630 tubes are to be fabricated and tested before Stage I operation is initiated.

b) After the accelerator has achieved Stage I operation, the factory output will be adjusted to deliver approximately 175 new or re-processed tubes per month as follows for Stage I operation (based on an assumed average operating lifetime of 2,000 hours):

1)	New tubes for replacement	10 tubes/month
2)	Major repairs	30
3)	Cathode replacements and/or other minor repairs	135
	Total	175

C. KLYSTRON REQUIREMENTS, STAGE I AND STAGE II

1. The 630 tubes in circulation during Stage I will be distributed approximately as follows:

a)	Tubes on accelerator	480
b)	Standby for accelerator use	~ 40
c)	In transit	~ 10
d)	In factory being repaired	~ 100
	Total	630

2. During the transition period from Stage I to Stage II operation, 40 new tubes per month will be constructed, in addition to maintaining the existing complement, until a total of ~ 1,200 tubes are in circulation, at which time Stage II operation may begin.

3. After the initiation of Stage II operation, the factory schedule will be approximately as follows:

a) New tubes for replacement	~ 25 tubes/month
b) Major repair	~ 60
c) Cathode replacements and/or other minor repairs	~ 270
Total	355

4. Of the ~ 1,200 tubes in circulation during Stage II operation, the distribution should be as follows:

a) On accelerator	920
b) Standby	~ 70
c) In transit	~ 20
d) In factory being repaired and tested	~ 190
Total	1,200

D. KLYSTRON SPECIFICATIONS

1. The Main Power Amplifier. The specifications for this tube are based on the existing Stanford klystrons and are given in Tables 1 and 2.

2. The Klystron Driver Tubes. These will be of a commercially available tube having an output of 1 - 2 megawatts peak power, such as the Varian V-87.

E. KLYSTRON ASSEMBLY AND PROCESSING

Estimates of the personnel, space, and time requirements for the manufacture of klystron parts, their assembly into completed tube structures,

TABLE IV-B-1. General specifications for the main power amplifiers
(based on the present Mark III accelerator klystrons.)

Perveance	1×10^{-6} amp/$v^{3/2}$
Heater power	500 - 650 watts, AC
R-f load	Matched S-band waveguide (RF-48/U)
Frequency	2856 Mc/sec
Type	3-cavity (4-cavity*)
Vacuum	Sealed-off
Mounting	Plug into coils and socket, body grounded
Cooling	Water
Weight	135 lbs, including present focusing coils (80 lbs without focusing coils**)
Height	49 in. (53 in.*)
Diameter	13 in. (7 in.**)
Connections:	
Cathode-Heater	Special socket
Inpute (r-f)	Type HN-Connector
Output (r-f)	Special waveguide flange (waveguide under vacuum of 10^{-7} mm Hg or better)
Water	2 hoses
Shielding (X-ray)	187 lbs lead
Pulse length	2 μsec, flat-top
Life	> 2,000 hours
Focusing	Electromagnetic (plug in coils external to tube)

*These figures are based on the possible use of a four-cavity klystron.

**These figures apply if plug-in focusing coils are used.

TABLE IV-B-2. Operational data for main klystron amplifier
(For reference, data on operation at 22 Mw are also given.)

**These figures apply if plug-in focusing coils are used.

TABLE IV-B-2. Operational data for main klystron amplifier
(For reference, data on operation at 22 Mw are also given.)

Item	Stage I 6 Mw level	Stage II 22 Mw level
Pulses per second	360 pps	60 pps
Power output	6 Mw	22 Mw
Beam voltage	200 kv	305 kv
Beam efficiency	32 %	42 %
Power gain	27.5 db	30.5 db
Peak beam power input	18.5 Mw	52.5 Mw
Peak beam current	89 amp	170 amp
Impedance	2250 ohms	1790 ohms
Average beam power	15.1 kw	7.2 kw
Focus power	900 watts	1.4 kw
Water cooling	4 gal/min	2.5 gal/min

and for the processing and sealing-off of the tubes, have been based upon the following premises:

1. The main power amplifiers will be essentially the same as those presently used on the existing Stanford accelerators except that they will be sealed-off, and will be modified mechanically to facilitate production and to allow interchange of the tubes on the accelerator. A summary of these specifications has been given in detail in Tables IV-B-1 and IV-B-2.

2. The operating level of the accelerator will be chosen so that the average operating life of the klystrons will be equal to or greater than 2,000 hours.

3. The processing of klystrons (to be described later) will follow procedures that have been previously used at Stanford (and by other manufacturers of such large tubes).

4. Extrapolating the current experience with the fabrication of klystrons for the Mark III accelerator, the machine shop and tube assembly shrinkage would total approximately 40%. However, some cathode assembly parts may be salvaged and reused, on an average, through 6 repair cycles.

5. The current shrinkage through baking and processing tubes is 15%. The present indications are that this figure would not be substantially reduced by production methods. A figure of 15% has therefore been used for the estimates in this proposal.

6. The klystron factory and processing will operate on a one-shift per day basis during Stage I and on a two-shift per day basis during Stage II operation of the accelerator.

Since the processing of klystrons is an important part of the successful operation of an electron linear accelerator, the following description of this procedure has been included in this report.

The processing of klystrons will follow procedures which have been

used at Stanford and by other manufacturers of such large tubes. Except for the high temperature outgassing (baking) of the tube, which is largely automatic, the processing for Stage I will be on a one-shift per day basis. This provides a cushion of two possible extra shifts in the event of manufacturing difficulties, which occasionally occur in this comparatively new industry.

A typical processing program for a large klystron is: one day to mount on the vacuum pumps, outgas the cathode and prepare for a high temperature bake; a 24-hour baking period during which the cathode is converted to provide proper electron-emission characteristics; and two 8-hour shifts on a modulator during which the voltage and power are raised above the anticipated operating levels of the accelerator. The tube is then checked for r-f performance, sealed-off, and stored for accelerator use.

In order to satisfy the accelerator requirements during Stage I, the klystron factory must process approximately 175 usable tubes per month; approximately 355 tubes are required per month for Stage II operation. The equipment needed for this schedule (if a 15% maximum shrinkage figure is used) is given below:

Processing modulators	20
Bake stations	10
R-F test units	10
Package units*	40

This will allow the factory to process 20 tubes every two days, of which 17 can be expected to be satisfactory for machine operation. With no increase in equipment, the rate of processing can be tripled, should

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*A package unit is a portable table equipped with the necessary vacuum and water cooling provisions for a klystron while it is being processed.

the need arise, by simply adding two extra shifts. If the baking time is too long, more bake stations and package units (plus space) must be added. Other items related to these are noted in Section V under cost estimates. During Stage II, two processing shifts are anticipated, plus additional bake stations and package units to handle the extra tubes.

A working area of roughly 6,000 sq ft and a staff of approximately 20 technicians per shift will be required for processing. This processing area is based on the present experience and was arrived at by adding the total areas required for each operation (including equipment) plus an additional 25% for aisle space. Improvements in tube construction, more extensive use of ceramics, higher-temperature exhaust, and other technique changes should result in an improved life performance (> 2000 hours) and in a shorter, simpler, and cheaper processing cycle.

APPENDIX IV-C

Site and Buildings

This section gives a brief description of the facilities that must be housed for a linear accelerator of the type described in this proposal. The site under consideration is also described. This description is supplemented by a few illustrations.

A. BRIEF DESCRIPTION OF THE FACILITIES TO BE HOUSED

The multi-Bev accelerator facility, as it is presently planned, would consist of the following sections:

1. The Accelerator. This consists of an electron injection gun followed by the accelerator tube, which would be accommodated in a tunnel structure 10,000 ft long, and 10 ft square with a dome 3 ft high. The accelerator will be level, and will be 3 ft above floor level. Parallel with this tunnel, but 35 ft away, will be another similar structure 24 ft wide and 10 ft high with a dome 12 ft high, which is to contain the power sources, vacuum-pumping systems, control circuitry, etc. These tunnels are to be connected periodically as follows: (1) at 250 ft intervals along the length by 5 × 9 ft offset drifts for personnel access and for vacuum and water lines; and (2) at 10 ft intervals by 8 in. diameter tubes for r-f power transmission.

2. The Beam Switchyard. This is the area in which the electron beam from the accelerator is diverted to one or another of the target areas in the End Station. The emergent beams should be kept at the same level as in

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the accelerator, but here the accelerator will be 5 ft above floor level. The beam-switching area will be 600 ft long. This equipment will also be housed in a tunnel.

3. The End Station. This area, in which a number of target installations would be located, is described in Section IV. In this area, the beams will be kept at the same level as before.

4. Other. Various fabrication, maintenance, and equipment houses, as well as storage and handling facilities will also be needed.

B. SITE DESCRIPTION

It should be noted first that there are few sites available at Stanford or anywhere on the San Francisco Peninsula for an installation 12,600 feet long. Such a site exists, however, at Stanford in the hills to the southwest of Foothill Road. This site is indicated in outline on the aerial photograph (Frontispiece) and on the contour map (Fig. IV-C-1).

While it is contemplated that the actual width of the accelerator structure, consisting of two parallel tunnels, would be about 70 ft, it is believed desirable to have available a strip 1,000 feet wide for the first 10,000 ft. The area involved is 230 acres. The beam switching and target areas increase the length of the planned installations to a total of 12,600 ft. A much greater width is needed here than along the accelerator for three reasons: (1) The multi-Bev particles produced by the accelerator are highly relativisitic, and the equipment required to deflect and study them is necessarily very large. (2) Much

of the area must be devoted to shielding against radiation; such shielding would take the form of walls, mounds, or open space (for air scattering). (3) It is impossible to predict what type of experiments will be most fruitful, and it is likely that space requirements for some future experiments will exceed those of experiments now being considered; hence, it is desirable to reserve a large area for experimental purposes. It is therefore estimated that a tract of about 150 acres will be needed for the Switchyard and End Station areas. Figure IV-C-2 shows a possible layout of this tract.

C. BUILDINGS, AND GROUNDS DEVELOPMENT

Table IV-C-1 presents in some detail the estimated requirements for buildings, utility areas, parking, roadways, etc. These will occupy approximately 30 acres.

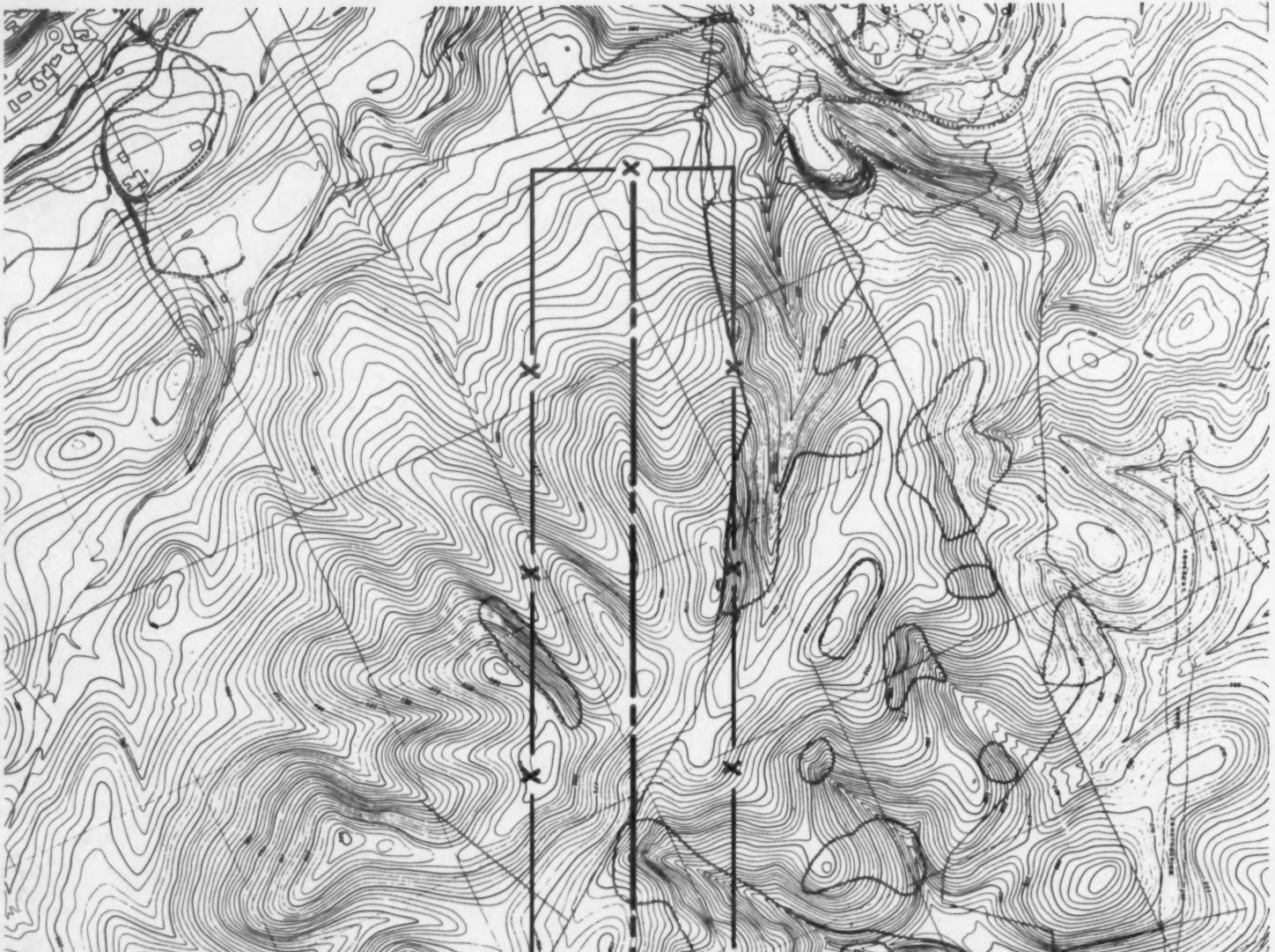
D. NOTES CONCERNING THE SITE

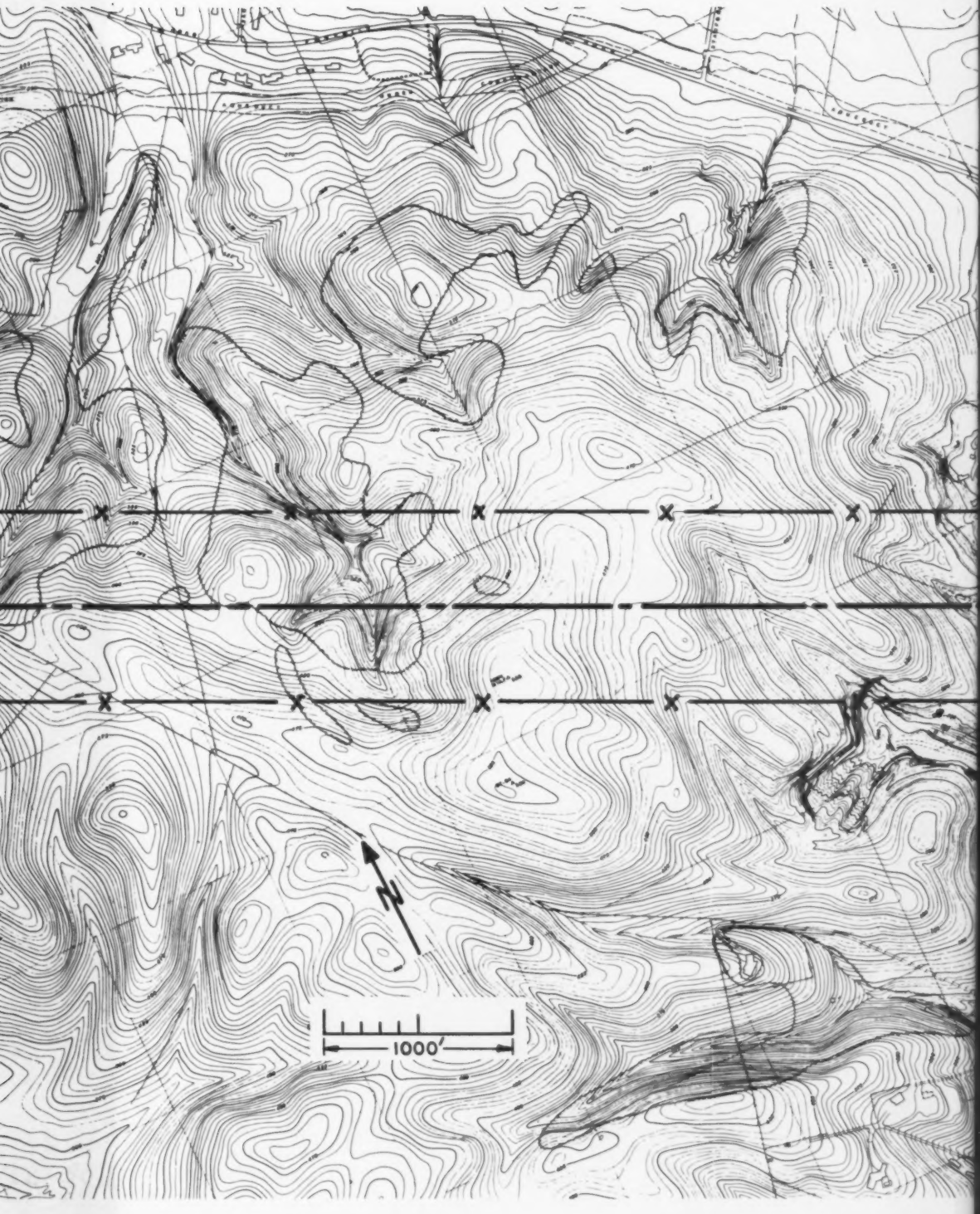
The terrain is hilly, and the proposed site is crossed by (1) three creeks, of which one--that at Page Mill Road--is sizable; and (2) by Page Mill Road itself. The accelerator crossing at Page Mill Road is an expensive undertaking, but can be quite readily accomplished.

TABLE IV-C-1. Buildings and Grounds Development

A.	**Buildings by Type:**		
1.	**Equipment and Materials Storage:**[1]		sq. ft.
	a. Accelerator	10,000	
	b. Klystron factory	2,500	
	c. Research	3,000	
			15,500
2.	**Observation and Service Buildings:**[2]		
	a. Observation houses	8,000	
	b. DC generator and magnet control vaults:		
	1) Beam switchyard	3,000	
	2) Research	18,000	
	c. Emergency power plant (accelerator lighting and ventilating)	1,000	
	d. Receiving, Stores, Inventory	5,000	
			35,000
3.	**End Station "Test House":** with crane supports and rails, heavy floor with utility trenches		200,000
4.	**Shop Space:**		
	a. Accelerator: Machine and electroforming shops	23,000	
	b. Accelerator: Mechanical and electrical maintenance shops	13,000	
	c. Klystron factory: Machine, brazing, etc. shops	20,000	
	d. Research: Machine, welding and brazing shops	9,000	
	e. Buildings and grounds equipment shops	8,000	
	f. Heating plant	3,000	
	g. Mobile stock garage	1,000	
			77,000
5.	**Laboratory Space:**		
	a. Accelerator control room	5,000	
	b. Accelerator prototypes	13,500	
	c. Klystron factory: Assembly, electroplating, inspection, etc.	7,500	
	d. Research: Physics Laboratory	10,000	
	e. Research: Electronics shop	6,000	
			42,000

[1] Simple construction, much like warehouses.
[2] Like above, but with semi-finished interiors.

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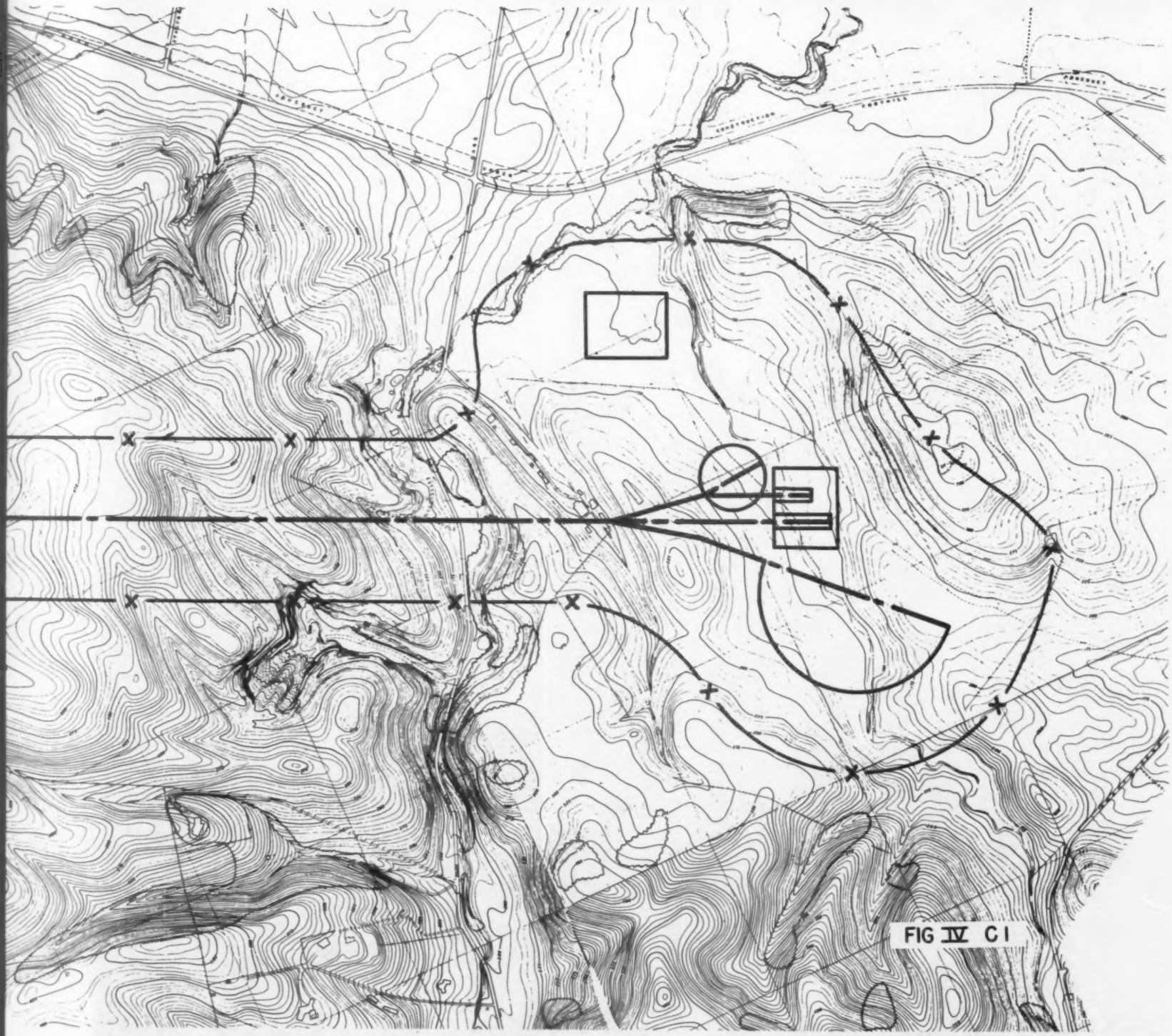


FIG IV C 1

6. Offices:		sq. ft.		
a. Physicists and engineers	5,000			
b. Klystron factory	3,000			
c. Administration and general services	16,000			
Sub-total, Buildings -		24,000		
				393,500
B. Outdoor Utility Areas:				
1. Storage and Plant Facility:				
a. Bricks and general material storage - Research	20,000			
b. Material storage-Accelerator	10,000			
c. Oil storage - Accelerator; buried in ground	4,000			
d. Recirculating water - Experimental houses; 3000 sq ft at each house	9,000			
e. Recirculating water - Accelerator; for 2-mi length of accelerator	30,000			
f. Recirculating water - Klystron factory	1,000			
g. Power substation	10,000			
h. Material storage - Klystron factory	5,000			
i. Corporation Yard storage	5,000			
		94,000		
2. Parking, etc.		90,000		
3. Roadways, setbacks, site grading, etc.		725,000		
Sub-total, Outdoor Utility Areas -				909,000
TOTAL -				1,302,500 sq ft

43633 O - 59 (Face p. 417)

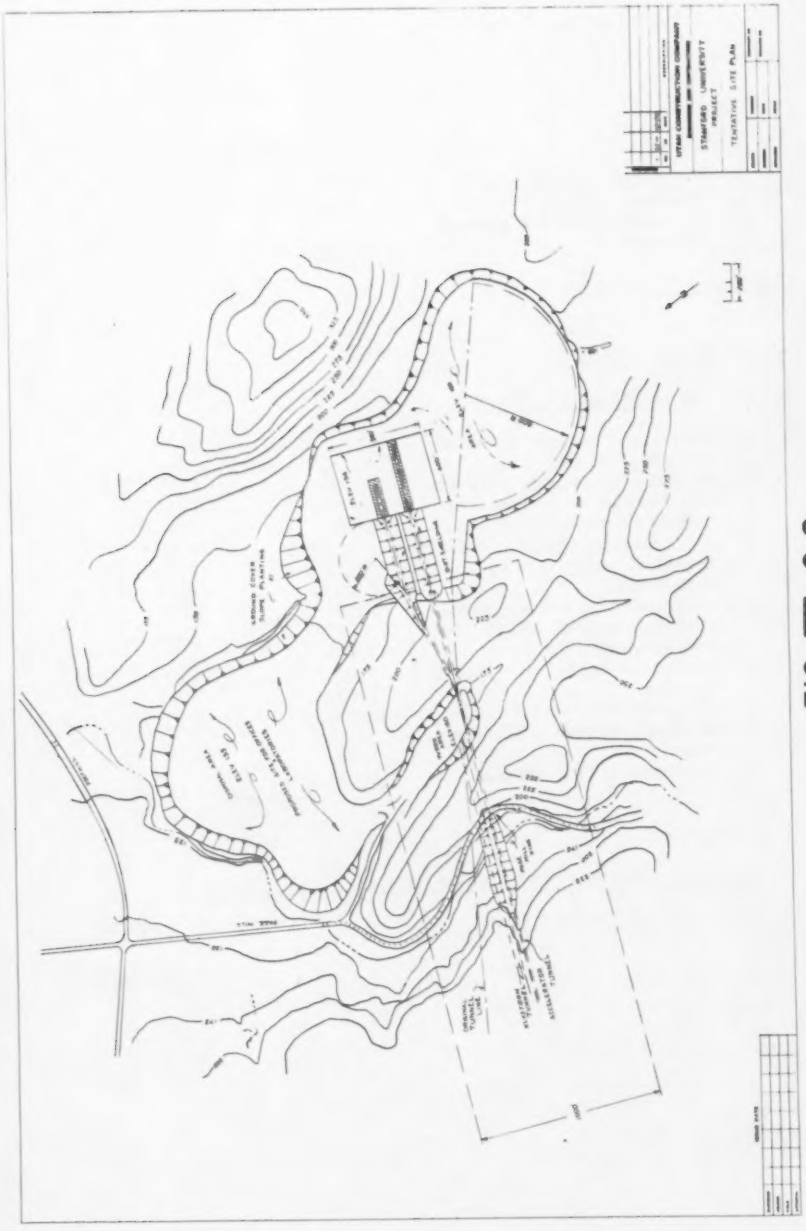


FIG IV C 2

APPENDIX IV-D

Description of AC Power Distribution System

A. SUMMARY OF POWER REQUIREMENTS

An estimate of the installed power capacity required for the various areas of Project M is given below.

	Stage I	Additional for Stage II	Total for Stage II
1. Accelerator and Klystron Tunnels			
Modulators (estimated from specifications of modulators, ~ 80% effective)	9,910 kva	0	9,910 kva
Auxiliary equipment for accelerator and modulators	3,700	0 or ?	3,700
Lighting of tunnels (assumes 4 w/sq ft in klystron tunnel, 2 w/sq ft in accelerator tunnel)	1,400	0	1,400
Total	15,010	0	15,010
2. Beam Switchyard			
AC power to run the DC generators for the deflecting magnets (estimated from a rough design of deflecting magnets)	2,500	0	2,500
Auxiliary equipment (vacuum pumps and lights; estimated by rough computation of number of vacuum pumps required plus 4 w/sq ft for lighting	300	0	300
Total	2,800	0	2,800
3. End Station (one target house of 200,000 sq ft)			
Lighting (4 w/sq ft)	800	0	800
Misc. installed power capacity (crane, outlets, welding, etc.; estimated on the basis of desired convenience and approximate scaling of Mark III end station)	1,500	0	1,500
Electronics, etc. (required for experiments, estimated on the basis of Mark III experience)	1,500	500	2,000
Total	3,800	500	4,300 kva

It is not planned to initially install sufficient AC capacity for the large DC generators which will eventually be used in the end station. However, underground conduit boxes from the main sub-station sufficient to carry 10,000 kva will be reserved for this purpose.

4. Power Requirements for the Administration Building, Shops, and Laboratories (exclusive of the end station facilities)

	Stage I	Additional for Stage II	Total for Stage II
Total installed capacity	5,000 kva	0	5,000 kva

To estimate the power required for this installation, we consider the building areas listed in the site and buildings Appendix IV-C, Item 1, which contains the following figures:

Shop	77,000 sq ft	
Labs	42,000 sq ft	
Offices	24,000 sq ft	(exclusive of end station)
Warehouses	50,000 sq ft	
Total	193,000 sq ft	

We estimate the power requirements for building of this type as follows:

Lighting	770 kva
Nominal installations of convenience outlets, 1000 outlets at 20 amps for each 5 outlets	480
Klystron Shops	900
Accelerator machine shops (estimated from machine and electroplating requirements)	240
Laboratories - 35,000 sq ft (estimated as 10 w/sq ft on basis of Mark III electronics + counter labs)	420
Prototypes and auxiliary equipment	2250
Total	5060 kva

5. Outdoor lighting and lighting for utility areas

	Stage I	Additional for Stage II	Total
	500 kva	0	500 kva

(Very rough approximation, but this requirement should be a small fraction of the total.)

SUMMARY

Accelerator	15,010 kva	0	15,010 kva
Beam Switchyard	2,800	0	2,800
Target House	3,800	500	4,300
Admin., Shops, and Labs	5,000	0	5,000
Outdoors, etc.	500	0	500
Grand total	27,110	500	27,110 kva

B. POWER DISTRIBUTION SYSTEM

The planned AC power distribution system is comprised of a main feeder and a main substation and seven local distribution systems as described below. A diagram indicating the main cable runs is shown in Fig. IV-D-1.

1. Main Feeder. The Pacific Gas and Electric Company has studied the problem of bringing power to the Project M site. They propose to bring in two lines (one from Los Altos and one from Menlo Park) at a voltage of 66 kv. At the main substation, the voltage will be reduced to values suitable for transmission in underground cable.

2. Description of Substation Components.

a) Main (28,000 kva required)

2 - 14,000 kva 66 kv air circuit breakers

2 - 14,000 kva 66 kv/4 kv transformers

12 -- 4 kv air circuit breakers

Meters, controls, etc.

b) Accelerator substations (four in all, total 16,000 kva). These are very rudimentary substations containing only circuit breakers. They should be equally spaced along the length of the accelerator; perhaps they should be inside the klystron tunnel. Each substation feeds five 4 kv lines to supply 10 power supplies and auxiliary power for 2,500 ft of accelerator. The transformers to 208 v will have to be inside the tunnel. The accelerator substation contains five 4 kv air circuit breakers.

c) Beam Switchyard Substation (2,800 kva)

5 - 4 kv air circuit breakers

1 - 4 kv/208 v 300 kva transformer

10 - 208 v breakers

Meters, etc.

d) Substation for the Administration Building, Labs, Shops, and Outdoor Lighting, (5,500 kva).

1 - 4 kv air circuit breaker

2 - 4 kv/208 v 3,000 kva transformer

100 - 208 v breakers

Meters, etc.

e) End Station Target House Substation (3,800 kva, Stage I, 4,300 kva, Stage II)

2 - 4 kv air circuit breakers

2 - 4 kv/208 v 2,000 kva transformer

20 - 208 v breakers

Meters, etc.

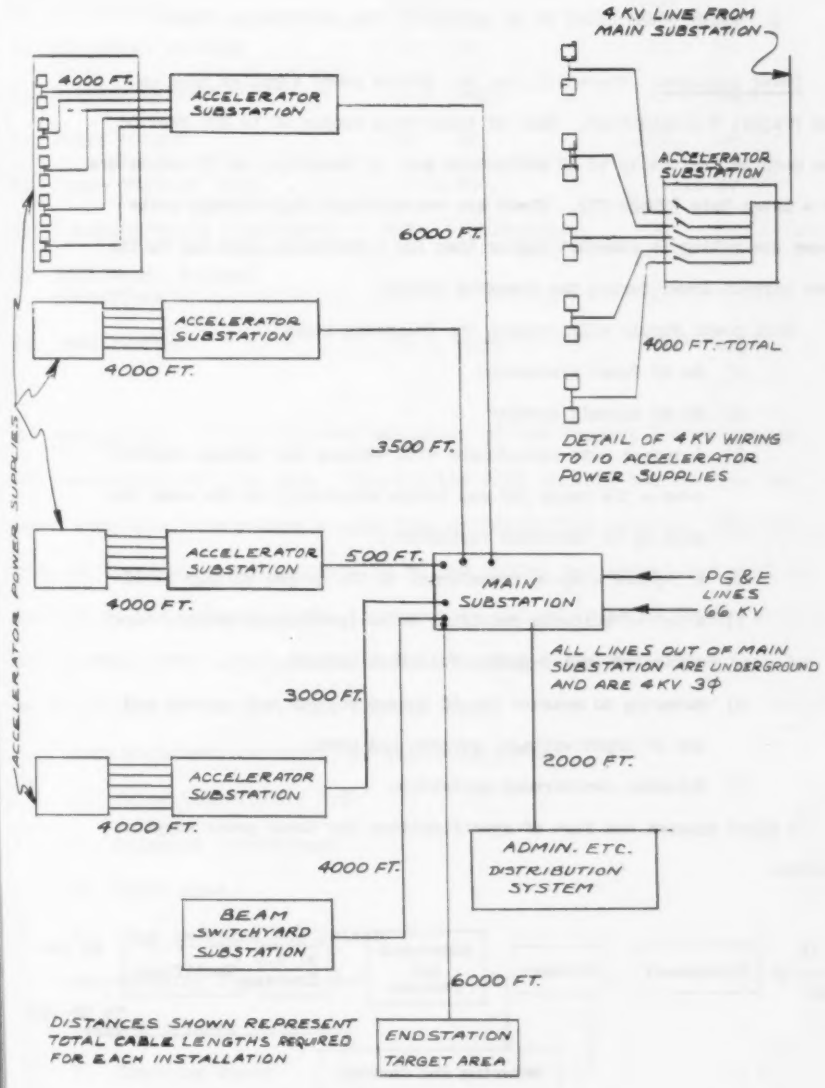


Fig. IV-D-1. Power Distribution System

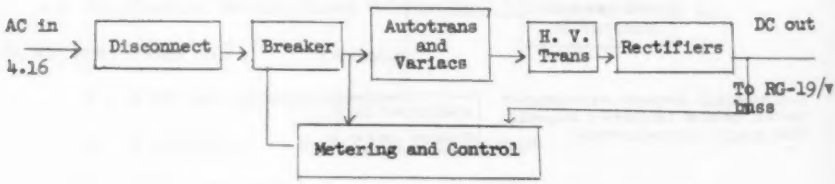
C. MAJOR POWER UNITS TO BE LOCATED IN THE ACCELERATOR TUNNEL

1. Power Supplies. There will be 40 200 kw power supplies used on the Project M accelerator. Each of these will supply DC to 250 feet of the machine, initially to 12 modulators and, if feasible, to 23 modulators at a later date (Stage II). These are conventional high-voltage units whose kva rating is somewhat higher than for a resistive load due to the peak current drawn during the charging cycles.

Each power supply will contain the following items:

1) An AC fused disconnect
2) An AC circuit breaker
3) A tapped auto-transformer with variacs for voltage control over a 30% range (or any device which will do the same job, such as an induction regulator.)
4) A 3-phase step-up transformer to the proper voltage level.
5) A set of suitable rectifier tubes (preferably mercury-vapor connected in a 3-phase, full-wave circuit.
6) Metering to measure the DC output voltage and current and the AC input voltage, current and power.
7) Suitable overcurrent protection.

A block diagram and list of specifications for these power supplies follows:



Specifications	Stage I	Stage II
1) DC output voltage	9.0 kv	13.7 kv
2) Average current	21.8 amps	13.6 amps
3) Power output	196 kw	188 kw
4) Input voltage (AC)	4.16 kv	4.16 kv
5) Charging cycle (resonant)	360 cycles/sec.	60 cycles/sec.
6) Full wave, 3-phase rectifiers	---	--
7) Peak current	34.2 amps	21.4 amps

2. Modulators. In the initial operation of the Project M accelerator, 480 modulators will be used. These units will convert the DC from the power supplies into pulses 2 μsec long on their flat portion. The pulse rate of these units will initially be 360 cycles per second but will be reduced as the voltage on the klystrons is raised so as to remain within the initial power supply rating. The charging choke may either have to be adjustable or changed when this is done.

Each modulator contains the following items:

1) Pulse transformer 1:24
2) Filament transformer
3) Pulse line
4) Plug in spark gap switch
5) Charging choke
6) Gap trigger
7) Charging diode
8) Circuit breaker
9) Disconnect switch

10) Trigger booster amplifier

11) Focus supply

12) Klystron focusing coils and X-ray shielding

13) Klystron socket

All of these items are mounted in or on a stainless steel tank which can be rolled into position. This permits easy interchange of defective units. Those items most subject to failure (the gap, charging diode and klystron) can be replaced without removing the module. It is felt that this equipment can be packaged in a 4 x 5 ft area; the height would be about 6 feet.

REVIEW

OF THE

STANFORD PROPOSAL

FOR A

TWO-MILE LINEAR ELECTRON ACCELERATOR

JUNE 1958

This document serves to asses the cost of constructing and operating the accelerator originally proposed by Stanford University in 1957, and does not analyze specifically the cost of the accelerator currently under consideration.

WILLIAM M. BROBECK & ASSOCIATES

1920 Park Boulevard
Oakland 6, California
Phone GLencourt 2-0876

INTRODUCTION

A. Statement of Work

This report is submitted in fulfillment of Atomic Energy Commission contract No. AT(04-3)-227, dated June 3, 1958. Under this contract William M. Brobeck & Associates, Oakland, California, assisted by their sub-contractor, Kaiser Engineers, Division of Henry J. Kaiser Company, Oakland, California, is required to prepare:

1. An estimate of the construction costs of the complete two-mile Linear Electron accelerator as defined below through Stage II.

2. An estimate of construction costs of Stage I of the project and a comparison with that contained in the Proposal.

3. A brief review of the annual recurring costs included in the Proposal.

It should be noted, as pointed out in Dr. Panofsky's letter to Dr. John H. Williams, dated June 4, 1958, that Part I of this report goes beyond the Stanford Proposal. Their proposal specifically proposed the construction of a Two-Mile Accelerator in the Stage I version. This report, as can be seen from the above, includes an estimate of costs through Stage II. It further provides estimates of the University overhead allocation whereas the Stanford Proposal noted that funds would be required but did not include estimates.

This report also changes some of the design assumptions in the Stanford Proposal as summarized later. These changes resulted from recommendations either by Stanford, the engineers preparing this report or changed conditions since preparation of the Stanford report.

A somewhat different format has been used in presenting budgets and estimates to more closely fit the Atomic Energy Commission pattern.

B. Definition of Terms

1. "The Stanford Proposal" refers to the "Proposal for a Two-Mile Linear Accelerator," dated April 1957, prepared by Stanford University, Stanford, California.

2. "Stage I" and "Stage II" refer to phases of construction as defined by Stanford. Stage I includes the construction of a Two-Mile Accelerator powered by 480 Klystrons of at least 6 MW peak output R-F power each. It includes the installed power capacity, water circulation, site facilities and end stations required for both Stage I and Stage II. The primary differences are:

Introduction (Continued)

		Stage I	Stage II
a.	No. of Klystrons supplying power to the accelerator	480	920
b.	Beam energy	15 to 30 BEV	Approx. 45 BEV
c.	Repetition rate	360 cycles per sec.	60 cycles per sec.

3. "Costs of the Complete Accelerator" as used above is understood to mean a turnkey job including all construction costs to build an operable accelerator including project and University management and overhead costs. It further includes the auxiliary research facilities necessary for initial use of the machine.

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SUMMARY

1. Total Construction Costs

a. The total construction costs of the complete project through Stage II is estimated at $127,389,000.

b. The total construction costs for Stage I, is estimated at $115,996.000.

The following is a comparison of the Stanford costs for Stage I versus Brobeck estimates:

	Stanford	Brobeck
Costs estimated by Stanford	$ 78,071,000	$ 85,840,000
Additional Costs not estimated by Stanford	---	5,598,000
Escalation & Contingency	-*-	24,558,000
Total	$ 78,071,000	$115,996,000

Detailed comparisons of these costs are provided in subsequent sections.

2. Recurring Costs

a. The estimated recurring costs each year are:

	Stanford	Brobeck
Operating Costs	$ 10,038,000	$ 13,020,000
Plant & Equipment Costs	4,275,000	3,725,000
Total	$ 14,313,000	$ 16,745,000

3. Basis of Estimates

a. Time Scale: The estimates included herein are based on a construction schedule starting July 1, 1959, and continuing for a period of six (6) years to completion on June 30, 1965. Construction costs are based on present prices, plus estimates of escalation of 3.00% per year for accelerator components and 4.5% per year for construction items.

b. Accelerator Performance: Brobeck & Associates has assumed no responsibility for estimating the intensity, energy or other capabilities of the accelerator electron beam but has estimated the facilities necessary to achieve the proposed 90% operating factor assuming a reasonable startup period.

* Some escalation is included in the Stanford Proposal but amounts are not stated.

A study has been made of existing data on Klystron tube life. This study indicates that an improvement of a factor of two in reliability is needed to meet the specification of the Proposal. We agree that this improvement is reasonable to expect as a result of reduction of power output and an energetic tube development program. In our opinion, the facilities proposed will provide 90% innage at the initial power level.

4. Technical Design

In the preparation of these estimates our instructions were to follow the design specified in the Proposal except in those cases where the design appeared impractical or would result in excessive expense. In those cases we were to change the design, if possible, and estimate the costs based on the changed design. With minor exceptions we find the design proposed to be practical and not excessively expensive.

The Proposal specifications of this design which effect the costs are summarized in Table I. The departures from the design on which we have based our costs are listed in Table II.

The purpose of the design work undertaken was to provide the necessary basis for the cost estimate. No attempt was made to optimize the design other than to avoid solutions which required excessive costs. It would be expected that an optimized design would be less expensive than the one estimated. On the other hand, not all the design problems may have shown up during the brief period available for this study. Some features of the design may be unattractive from an operating point of view but in the cases that we know about the cost would not be affected appreciably by the changes.

Reproductions of the drawings on which our estimate is based are included in this report.

TABLE I

* BASIC DESIGN SPECIFICATIONS

Accelerator Length	10,000 Feet
Klystron Tunnel Cross Section	22 x 24 Feet
Accelerator Tunnel Cross Section	12 x 10 Feet
Number of Klystrons in Operating Positions	
Stage I	480
Stage II	920
Average DC Plate Power to Klystrons	9000 KW
Initial Peak Output RF Power per Klystron	6 MW
Number of Developed Beams	3
Site and Tunnel Location	As specified in Proposal

* Detailed specifications will be found in the appendices for corresponding parts of the project.

TABLE II

CHANGES FROM STANFORD PROPOSAL

1. No inflamable oil is to be used in the tunnels.

2. DC deflecting magnets and phase meters are to be used in place of pulsed deflecting magnets for phase adjustment.

3. A single 110 KV power line is estimated with provision for a future line instead of two 66 KV lines. This change has been necessitated by changes in the Pacific Gas & Electric Co. system since the Proposal.

4. Secondary power is distributed at 13.8 KV and 480 volts instead of 4160 volts for reasons of economy.

5. Additional office building space of 16,000 square feet is provided for engineering and service staff.

6. Alcoves are provided off the Klystron tunnel for the DC power supplies, control consoles, 480 volt substations and control cross-connect wiring.

7. Motor-generators and associated electrical equipment and structures are provided to supply 10,000 KW of DC power to the end station research equipment.

8. An initial complement of equipment for use in research with the machine is included.

9. Some advantage has been taken of multiplexing in the control circuits.

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II

SUMMARY

CONSTRUCTION COST ESTIMATE
COMPLETE TOTAL THROUGH STAGE II

Description	Estimate x 1000	Estimate x 1000
1. Site, Utilities, Buildings & Tunnels		
a. Engineering, Design & Supervision	$ 2,190	
b. Site Development	1,037	
c. Plant & Accelerator Utilities	8,978	
d. Tunnel Shafts	20,351	
e. Buildings	7,242	
f. Power Supply - Structures	1,900	
g. Building Partitions, Installed Equip., etc.	560	
h. Miscellaneous	274	$ 42,532
2. Accelerator Development		14,425
3. Accelerator Construction		
a. Engineering, Design & Supervision	$ 3,520	
b. Accelerator Tube & Accessories	3,169	
c. Radio Frequency System	19,522	
d. Beam Control System	846	
e. Vacuum System	3,650	
f. Beam Switching Magnets	426	
g. Control & Instrumentation	4,693	35,826
4. Construction, Research & Misc. Equipment		7,384
Sub-total		$100,167
5. Escalation		15,410
6. Contingency		11,812
Total through Stage II		$127,389

II

SCHEDULE A

SITE, UTILITIES, BUILDING AND TUNNEL ESTIMATE

		Estimate x 1000
1.	Engineering, Design and Supervision	
	Site Development	$ 240
	Plant Utilities	701
	Tunnels, Shafts, etc.	438
	End Stations	307
	Buildings	504
	Total	$2,190
2.	Site Development	
	Site Preparation	$ 568
	Road & Parking Areas	188
	Storm Drains	179
	Fencing & Landscaping	102
	Total	$1,037
3.	Plant & Accelerator Utilities	
	Water Supply and Storage	$ 98
	Cooling Water (Demineralized)	2,914
	Cooling Water (Raw)	315
	Compressed Air Facility	1,614
	Air Conditioning, Ventilation & Chilled Water	771
	Yard Electrical Work	3,234
	Miscellaneous Yard Utilities	32
	Total	$8,978

4. Tunnel, Shafts, Etc.	Sq. Ft.	Estimates x 1000
Accelerator Tunnel		$ 3,271
Klystron Tunnel		8,345
Vaults & Alcoves		1,521
Cross Drifts		371
Cross Bores		576
Shafts		493
Beam Switchyard		542
Miscellaneous Tunnel Piping		357
Tunnel Electric		4,875
Total		$20,351

5. Buildings		
End Station & Shielding	200,000	$5,251
Two-story Lab at End Station	41,000	611
General Service Building	14,000	112
Klystron Factory and Prototype Lab	46,500	432
Accelerator Storage & Shops	46,000	390
Administration Building	16,000	160
E & S Building	16,000	160
Accelerator Control House	5,000	126
Total		$7,242

6. D. C. Power Supply End Station (Includes Structure, Cooling Water & AC Power Supply)	$1,900

7. Building Installed Equipment, Installation and Miscellaneous

	Sq. Ft.	Estimate x 1000
End Station	200,000	$200
Two-story Lab at End Station	41,000	82
General Services Building	14,000	28
Klystron Factory & Prototype Bldg.	46,500	93
Accelerator Storage & Shops	46,000	93
Administration Building	16,000	32
E & S Building	16,000	32
Accelerator Control House	5,000	---
Total		$560

8. Miscellaneous

Klystron Heater Control Transformer	$ 34
Steel Beam Backstops	240
Total	$274

Grand Total - Schedule A $42,532

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II

SCHEDULE B

ACCELERATOR DEVELOPMENT

Description	Estimate x 1000	Estimate x 1000
1. Prototype Laboratory Construction		
Prototype Accelerator (160 ft.)	$ 908	
Component Test Stands (10)	762	
Klystron Life Test Stands (10)	500	
Equipment Utilities	305	
Sub-total	$ 2,475	
Engineering Design & Supervision 15%	325	
Klystron Tubes for Tube Development Program	500	$ 3,300
2. Prototype Laboratory Operation		1,100
3. Systems & Component Development		5,050
4. Production Development		
Klystron Production - 10 people for 6 yrs.	$ 940	
Accelerator Tube Production - 10 people for 3-1/2 yrs.	550	1,490
5. Scientific Staff		
4 people for 6 yrs.		385
6. Accelerator Startup		1,100
7. Miscellaneous Supplies		2,000
Total Accelerator Development - Schedule B		$ 14,425

II

SCHEDULE C

ACCELERATOR CONSTRUCTION

Description	Estimate x 1000	Estimate x 1000
1. Engineering Design & Supervision		
a. General Overall Design	$ 290	
b. RF System	1,038	
c. Vacuum System	1,060	
d. Liason with AE Firm	380	
e. Research Equipment	330	
f. Other	422	$ 3,520
2. Accelerator Tube & Accessories		
a. Electroforms	$ 2,313	
b. Cooling Jacket & Magnetic Shield	258	
c. Supports & Adjusting Mechanism	381	
d. Cooling Water Connections	217	3,169
3. Radio Frequency System		
a. Klystron Tubes (1200)	$ 4,800	
b. Klystron Modulator Cubicle (includes shields & focus coils)	10,228	
c. Klystron Modulator Cubicle Accessories (includes stand & water & air connectors)	762	
d. High Voltage Power Supplies (40)	1,044	
e. Klystron RF Input System	1,861	
f. Klystron RF Output Waveguide System (not including phase meter connections)	622	
g. Trigger System	205	19,522
4. Beam Control System		
a. Injector & Inflector System (40) (includes power supply & vacuum chamber)	$ 373	
b. Deflecting Magnet System (40) (includes supports, power supplies, vacuum chamber)	261	
c. Non-intercepting Beam Pickup Electrodes (including vacuum chamber)	13	
d. Degaussing System	36	
e. Steering Magnets & Supports	108	
f. Focusing Magnets & Supplies	55	846

Description	Estimate x 1000	Extimate x 1000
5. Vacuum System		
a. Diffusion Pumps	$ 239	
b. Mechanical Pumps	335	
c. Valves, Traps & Expansion Joints	1,181	
d. Piping & Pipe Supports	1,895	$ 3,650
6. Beam Switching Magnets & Focusing Magnets		426
7. Controls & Instrumentation		
a. Communications	$ 42	
b. Central Klystron Monitors	395	
c. Miscellaneous Control Equipment	1,211	
d. Control Wiring & Consoles	1, 355	
e. High Speed Signal Coax	135	
f. Phase Meter System	449	
g. Vacuum Gages	1,020	
h. Vacuum Valve Indication & Controls	86	4,693
Total		$ 35,826

II

SCHEDULE D

CONSTRUCTION, RESEARCH AND MISCELLANEOUS EQUIPMENT

		Estimates x 1000	Estimates x 1000
1.	Klystron Factory Equipment (Appen. IV)		
	a. Machine Shop	$ 450	
	b. Tube Assembly	175	
	c. Tube Processing	610	
	d. Stage II - Additional	135	
	Total		$1,370
2.	Accelerator Tube Manufacturing Equip. (Appen. V)		
	a. Electro forming Facilities	$ 397	
	b. Machine Shop	250	
	c. R-F Test Equipment	37	
	Total		$ 684
3.	Construction Tools and Test Equipment		
	a. R-F Test Instruments(Accelerator)	$ 504	
	b. Vacuum and Mechanical Test Instruments	176	
	Total		$ 680
4.	All Other Research and Test Equipment	$1,912	
	Total		$1,912
5.	Hauling & Handling Equipment		
	Trucks and Fork Lifts	$ 55	
	Cars and Miscellaneous	15	
	Total		$ 70
6.	Major Research Equipment		
	a. Counting Equipment	$ 198	
	b. Research Magnets	1,000	
	c. Unspecified Large Research Equipment	1,000	
	Note: D. C. Generators Plant Estimate		
	Total		$2,198

7. All Office Furniture and Equipment	$ 470
Total Construction, Research and Miscellaneous Equipment	$ 7,384

SCHEDULE E

Escalation

Site, Utilities, Building and Tunnels	$8,000	
Accelerator Development	2,000	
Accelerator Construction	4,500	
Construction, Research and Miscellaneous Equipment	910	
Total		$15,410

SCHEDULE F

CONTINGENCY

Site, Utilities, Building and Tunnels	$7,452	
Accelerator Development	2,310	
Accelerator Construction	2,050	
Total		$11,812

III

SUMMARY
CONSTRUCTION COST ESTIMATE

Comparison with Stanford Estimate

Description	Stanford Estimate x 1000	Stanford Estimate OH Prorated x 1000	Brobeck Estimate x 1000
A. Accelerator Design, Fab. & Test			
1. General Design, Engr. & Test	$ 13,490	$ 18,024	$ 15,470
2. Power Facilities	11,048	12,558	15,869
3. Prototype Units	1,554	1,810	2,475
4. Accelerator Proper	6,427	7,762	11,751
5. Klystron Amplifier, 6 MW	2,619	3,184	2,681
6. Beam Switch Yard & End Station	750	846	861
7. Control & Instrumentation	6,748	7,298	5,271
Total	$ 42,636	$ 51,482	$ 54,378
B. Equipment			
1. Fabrication & Test	$ 5,000	$ 5,133	$ 4,511
2. Hauling & Handling	974	974	1,146
3. Furniture, Storage & Office	310	310	470
4. Major Research	---	---	---
5. Initial Complement	---	---	4,098
Total	$ 6,284	$ 6,417	$ 10,225
C. Administrative & General Services	$ 7,478	Prorated	
D. Tunnels, Buildings & Grounds	$ 21,672	$ 21,672	$ 26,835
E. Reimbursement to the University	*	Prorated	
Sub-total	$ 78,071	$ 79,571	$ 91,438
F. Escalation	---	---	$ 13,156
G. Contingency	---	---	$ 11,402
Total	$ 78,071	$ 79,571	$ 115,996

* Not estimated by Stanford.

SCHEDULE A-1

GENERAL DESIGN, ENGINEERING & TEST

	Stanford Estimate x1000	Stanford O. H. Prorated Estimate x1000	Brobeck Estimate x1000
Engineers:			
General Specifications	$ 224	$ 312	$ 145
Klystron Tubes and Factory	310	432	
Klystron Production Engineer			190
Accelerator Tube Production Engineer			110
Power Supply Design	310	432	10
Controls and Instrumentation (Design)	474	661	90
Specific Design & Components Tests	2,112	2,943	580
Liason with AE Firm			260
Prototype Design Engineer			160
Experimental Equipment Design			160
Prototype Facility Oper.			220
Systems & Components Dev.			2,020
Start Up			300
	$ 3,430	$ 4,780	$ 4,245
Supporting Staff:			
Draftsmen	$ 1,236	$ 1,723	$ 2,600
Laboratory Technicians	4,362	6,084	
Machinists	1,236	1,723	
Electricians	618	862	
Electronics Technicians	618	862	
All Technicians & Trades			5,740
Total Supporting Staff	$ 8,070	$11,254	$ 8,340
Scientific Staff:			$ 385
Purchases	$ 1,990	$ 1,990	$ 2,000
Klystron Tubes for Life Tests			500
Total	$13,490	$18,024	$15,470

SCHEDULE A-2

POWER FACILITIES

Description:	Stanford Estimate x1000	Stanford O. H. Prorated Estimate x1000	Brobeck Estimate x1000
P. G. &E. Line	$ 310	$ 310	$ 258
Substations and Feeders A. C.	2,158	2,158	7,207
D. C. Cable Accelerator	26	32	
D. C. Modulator and Power Supply Cubical	7,289	8,576	6,793
Special Wiring - Interior & Alarm	1,265	1,482	21
Compressed Air for Space Gap			1,590
Total	$11,048	$12,558	$15,869

SCHEDULE A-3

PROTOTYPE UNITS

Components and Installation	$ 1,171	$ 1,427	$ 1,508
Shielding	383	383	162
Utilities			305
Klystron Life Test Stand			500
Total	$ 1,554	$ 1,810	$ 2,475

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III

SCHEDULE A-4

ACCELERATOR PROPER

Description	Stanford Estimate x 1000	Stanford Estimate OH Prorated x 1000	Brobeck Estimate x 1000
Accelerator Pipe Sections	$ 2,564	$ 3,401	$ 2,571
RF Couplers & Installation	335	457	160*
Waveguide (all)	690	775	1,658
Windows	186	250	50
Vacuum Pumping System (to switchyard)	442	519	3,580
Cooling Water Manifolds	355	431	3,294
Cooling Water Recirculating System	1,640	1,650	
Accelerator Support	215	279	438
Total	$ 6,427	$ 7,762	$ 11,751

SCHEDULE A-5

KLYSTRON TUBES

Description	Stanford Estimate x 1000	Stanford Estimate OH Prorated x 1000	Brobeck Estimate x 1000
630 Klystrons	$ 1,856	$ 2,416	$ 2,520
480 Shields & Focusing Coils	763	768	161
Total	$ 2,519	$ 3,184	$ 2,681

* RF Coupler Integral With Accelerator Pipe.

SCHEDULE A-6

BEAM SWITCH YARD & END STATION

	Stanford Estimate x1000	Stanford OH Prorated Estimate x1000	Brobeck Estimate x1000
Deflection System	$ 406	$ 471	$ 426
Vacuum System	164	173	195
Cooling Water System	38	38	---*
Signal & Communications	142	164	--
Steel Plug Shield	---	---	240
Total	$ 750	$ 846	$ 861

*Not separated from the Accelerator Proper.

SCHEDULE A-7

CONTROLS & INSTRUMENTATION FOR THE ACCELERATOR PROPER (SCHEDULE A-4)

Consoles and Wiring	$ 1,684	$ 2,121	$ 1,097
R-F System	2,640	2,659	1,059
Trigger System	85	90	190
Inflection and Deflection Systems	638	675	632
Auxiliary Systems -- Includes Steering, Degaussing and Beam Pickup	1,701	1,753	213
Vacuum Gages	---	---	594
Communiations & Signals	---	---	102
Other Controls & Instruments	---	---	1,384
Total	$ 6,748	$ 7,298	$ 5,271

III

SCHEDULE B-1

FABRICATION & TEST EQUIPMENT

Description	Stanford Estimate x 1000	Stanford OH Prorated x 1000	Brobeck Estimate x 1000
A. Klystron Factory			
Parts Fabrication & Inspection Shops	$ 421	$ 426	$ 450
Tube Assembly	188	198	175
Tube Processing	609	705	610
Air Conditioning & Ventilation	35	35	-- *
Total	$ 1,253	$ 1,364	$ 1,235
B. Accelerator Proper			
Electro-forming	$ 364	$ 364	$ 397
Machine Tools	425	425	250
RF Test Equipment	37	37	37
Air Conditioning	1	1	-- *
Installation	128	150	-- *
Total	$ 955	$ 977	$ 684
C. All Other	$ 2,792	$ 2,792	$ --
1. Tools & Test Instruments for Accelerator Proper	--	--	600
2. Miscellaneous	--	--	1,912
Total	$ 2,792	$ 2,792	$ 2,592
Total Fabrication & Test Equipment	$ 5,000	$ 5,133	$ 4,511

* See Schedule D

III

SCHEDULE B-2

HAULING & HANDLING EQUIPMENT

Description	Stanford Estimate x 1000	Brobeck Estimate x 1000
Overhead Cranes & Trolley, End Station Test House, Beam Switch Yard & Research Machine Shop	$ 880	$ 877
Overhead Crane Prototype & Accelerator Laboratories & Shop	20	21
Tunnel Transportation	44	49
Tunnel Monorails (including rail)	--	102
Trucks, Fork Lifts, etc.	30	55
Tunnel Elevator	--	27
Cars	--	15
Total	$ 974	$ 1,146

SCHEDULE B-3

FURNITURE STORAGE & OFFICE EQUIPMENT

Description	Stanford Estimate x 1000	Brobeck Estimate x 1000
Bookkeeping Machines, Calculators, etc., for Accounting Office	$ 45	$ 30
Calculators, etc. Office	10	10
Furniture, Cabinets, Racks, Shelving & Office Equipment	255	430
Total	$ 310	$ 470

III

SCHEDULE B-4

MAJOR RESEARCH EQUIPMENT
INITIAL COMPLEMENT

Description	Stanford Estimate x 1000	Brobeck Estimate x 1000
DC Power - MG Set, DC Distribution, Cooling, AC & Structure for End Station Research	$ --	$ 1,900
Counting Equipment	--	198
Research Magnets	--	1,000
Unspecified	--	1,000
Total	$ --	$ 4,098

III

SCHEDULE D

TUNNEL, BUILDINGS, & GROUNDS DEVELOPMENT

	Stanford-Utah Estimate x 1000	Brobeck-Kaiser Estimate x 1000
1. Engineering & Design		
a. Engineering Design & Archit.	$ 1,094	$ 2,190
b. Geological Surveys & Exploration	53	--
Total	$ 1,147	$ 2,190
2. Underground Construction		
a. Klystron Tunnel	$ 5,980	$ 8,296
b. Accelerator Tunnel	1,930	3,190
c. Cross Drifts & Tubes between Tunnels	1,160	926
d. Ventilation & Escape Shafts	110	467
e. Tunnel Work in Switch Yard Area	297	522
f. Air conditioning in Tunnel	--	771
g. Vaults & Alcoves	--	1,522
h. Sanitary Sewer & Drains	--	230
Total	$ 9,477	$ 15,924
3. Plant & Surface Construction		
a. Page Mill Road Crossing	$ 365	$ --
b. Open cut work at 10,000 ft. point	40	--
c. Open cut work for End Station	685	567
Sub-total	$ 1,090	$ 567
d. Building Construction		
(1) Unfinished Warehouse	$ 93	--
(2) Semi-finished Warehouse	445	--
(3) Special Warehouse	2,720	3,384
(4) Shop Space	1,113	--
(5) Laboratory Space	885	--
(6) Offices	546	446
(7) End Station Lab. Bldg. (unfinished)	--	611
(8) General Services Bldg. (unfinished)	--	111
(9) Klystron Factory & Prototype (unfinished)	--	416
(10) Accelerator Storage & Shop (unfinished)	--	384
Sub-total	$ 5,802	$ 5,352
e. Shielding Bunkers		
(1) Inside Target House	$ 2,000	$ 1,020
(2) Steel Culvert & Backfill	425	--
	$ 2,425	$ 1,020

Description	Stanford-Utah Estimate x 1000	Brobeck-Kaiser Estimate x 1000
f. Outdoor Utility Areas	$ 485	$ 315
g. Parking Areas	45	--
h. Roadway Setbacks, etc.	290	188
I. Storm Drains	--	179
j. Water Supply & Storage	--	98
Sub-Total	$ 820	$ 780
Total	$ 10,137	$ 7,719
4. General		
a. Site Preparation, Facilities, etc.	$ 420	$
b. Security Fencing & Landscaping	194	101
c. Site & Security Lighting	79	--
d. Tunnel Lighting	218	341
Total	$ 911	$ 442
5. Building Installed Equipment		
a. Installation (For finishing of unfinished building except Research & Shop Equipment - Includes utility distribution, from stubbed-in lines, partitions, work benches, ventilation required by partitions, etc.)	$ --	$ 560
Total Site, Utilities, Buildings & Tunnels per the Stanford Report breakdown.	$ 21,672	$ 26,835

III

SCHEDULE E

ESCALATION

Description	Stanford Estimate* x 1000	Brobeck Estimate x 1000
Site, Area, Utilities, Buildings & Tunnels	$ --	$ 8,000
Accelerator Development	--	2,000
Accelerator Construction	--	2,286
Construction Research & Misc. Equipment	--	870
Total	$ --	$ 13,156

SCHEDULE F

CONTINGENCY

Description	Stanford Estimate x 1000	Brobeck Estimate x 1000
Site Utilities, Buildings & Tunnels	$ --	$ 7,452
Accelerator Development	--	2,310
Accelerator Construction	--	1,640
Total	$ --	$ 11,402

* Escalation allowance is included in Stanford figures provided by Utah Construction Co., but not identified.

IV

RECURRING COSTS

Estimates & Comparison with Stanford Estimates using Stage I Assumptions

A. Introduction

As agreed in the prime contract, the operating costs for the proposed accelerator have been reviewed briefly. The estimates presented herein are based on the assumptions that:

1. Maximum use be made of the accelerator from the AEC viewpoint both in terms of operating time and supporting personnel and facilities.
2. The operating period estimated is after the start up period.
3. Labor and material rates are based on 1960 prices, (per Stanford Proposal.)
4. AEC definitions were used for the cost breakdown indicated.
5. The Brobeck estimate of the University overhead allowance is included in the Brobeck column.
6. The estimate was based on a typical AEC contractor's mode of operation.
7. Non-recurring items were included in the construction estimates.

Item 6., was used as a basis for estimating since the Stanford assumptions are quite different than would normally be expected.

B. Summary - Annual Operating Costs

Operation	Personnel		*Dollars	
	Stanford	Brobeck	Stanford	Brobeck
Klystron Repair & Maint.	116	195	$ 1,731	$ 2,300
Accelerator Operation & Maint.	159	216	3,700	3,578
Research	274	346	2,255	3,285
Sub-total	549	757	$ 7,686	$ 9,163
Administrative & Gen. Services	178	242	1,704	2,407
University Overhead Allowance	---	---	---	250
Equipment not related to Const.	---	---	650	1,200
Total	727	999	$10,040	$13,020

* Shown in Thousands.

C. Summary - Annual Plant & Equipment Costs

The construction estimates include the initial complement of research equipment and plant items to support this. Even after the first few years of operation there will be a continuing demand for plant and accelerator improvements. These are divided into 1., General Plant Items, and 2., Line Items, according to the AEC use of these terms.

	Stanford	Brobeck
1. General Plant Items	*$ 1,050	*$ 1,000
2. Line Items	3,225	2,725
Total	$ 4,275	$ 3,725
D. Total Recurring Costs	$14,313	$16,745

E. Conclusions

Based on this brief survey, it is estimated that the total operating costs will be of the order of $13,000,000 for Stage I, as compared to Stanford's estimate of $10,000,000. Stage II operations will probably not exceed Stage I by more than $3,000,000. Since the Stage I estimate is based on a tube life of 2000 hours, actual costs may be as high as $15,000,000 if this tube is not achieved. On the other hand, if this tube life is exceeded the costs of both Stage I and Stage II will be correspondingly reduced. It is conceivable that Stage II operations should end up costing no more than Stage I if significant progress is made in increasing tube life or if it is found that running at a reduced power level with twice the number of tubes would result in an appreciable increase in tube life. It will be noted that the operating costs include an item for equipment not related to construction.

The recurring plant costs compare very closely. As noted in Appendix VII, we have included the initial complement in the construction estimate.

The overall recurring costs for operations and plant are higher by $2,432,000. This is due to the increase in operating costs. The total of $16,745,000 seems like a proper amount when compared to the capital cost of the machine.

* Shown in Thousands.

APPENDICES

I	Accelerator Design
II	Site, Utilities, Building and Tunnel Cost Basis
III	Prototype Facility
IV	Klystron Life and Production
V	Accelerator Tube Production
VI	Equipment Analysis
VII	Recurring Cost Analysis
VIII	Space and Personnel Analysis
IX	University Reimbursement

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APPENDIX I

SECTION A

ACCELERATOR COMPONENTS

1. Accelerating Tube and Accessories - Drawing D-11

   a. Accelerating Tube

   The accelerating tube costs are based on the electroformed construction in a factory built for the purpose as part of the project. The cost of the electroformed tubes includes the operating expense of this facility but does not include materials. After completion of the 1000 tube sections required, (920 used plus 80 spares), this facility would be available for further assignment. The basis of the accelerating tube production costs are presented in Appendix V.

   b. Accelerating Tube Accessories

   The accelerating tube is equipped with a stainless steel water-jacket which also supports the electroformed tube at two points in its ten foot length.

   The jacket is wound with two layers of mu-metal tape. The assembly is mounted on adjustable supports at each 10 foot joint. A single convolution bellows is provided between sections and each section is anchored longitudinally at the input end. The plates supporting the degaussing coil conduits are also used to support surveying targets and levels during alignment.

2. The Klystron Modulator - Drawings D-2 and D-8

   a. Power Requirements

   The Klystron filament supply requires 277 volts at 4 amperes. This is a separate circuit excited from a motor driven powerstat which enables all of the Klystron filaments within a 250 foot sector to be adjusted slowly from 30 per cent to full voltage. For individual adjustment, each Klystron modulator contains a filament variac.

   The remaining components derive their AC power from a 208 Volt, 3 kva, three phase circuit. The high voltage DC requirements are 9 kv at 1.8 amps for Stage I and 13.7 kv at 0.6 amps for Stage II.

   In addition to the electrical requirements, each Klystron cubicle will be supplied with 5 GPM of cooling water in

Stage I and 3.5 GPM in Stage II, and with 50 CFM dry air for the spark gap. These water quantities are slightly higher than required by the Klystron tube alone to provide cooling for other components.

b. Klystron Design Data

The Klystron modulator design was based on the following parameters: (From Table IV-B-2 of the Stanford Proposal)

Item	Stage I	Stage II
Pulses per second	360	60
Peak RF Power output	6 Mw	22 Mw
Beam voltage	200 kv	305 kv
Beam efficiency	32%	42%
Power gain	27.5 db	30.5 db
Peak beam power input	18.5 Mw	52.5 Mw
Peak beam current	89 amps	170 amps
Impedance	2250 ohms	1790 ohms
Average beam power	15.1 kw	7.2 kw
Focus power	900 watts	1.4 kw

c. Electrical Design of the Modulator

The above data permits a modulating pulse length of 2.3 microseconds. If the flat top portion of the pulse is to be 2.0 microseconds, at least seven sections are required in the pulse line. With the 24 to 1 pulse transformer as specified by Stanford, the surge impedance of the pulse line should be 3.12 ohms. The pulse voltage is 12.7 kv and the pulse current is 4080 amps. The resonant charging inductance was chosen to charge the line in 1/360 second which is required by the repetition rate of Stage I. For Stage II the same charging inductance is used; following a pulse, the line is charged within 1/360 second and waits 5/360 of a second for the next pulse.

The pulse line is charged from the incoming DC through a surge limiting diode, type GL 5973, which is a tube specifically designed for this purpose. The diode serves, also, to prevent power flow from the pulse line back into the DC power supply which would otherwise occur under fault conditions.

The Klystron modulator is a self-contained, self-protecting package. The protective equipment is designed to cope with three classes of faults -- (1) destructive faults, (2) non-destructive faults, and (3) self-healing faults. The first class consists of over-currents such as shorted pulse line capacitors. This class of fault removes all of the incoming power to the modulator. The second class of faults consists of over voltage which occurs in the event of loss of Klystron cathode emission or loss of Klystron filament current, and such things as open panel interlocks, loss of Klystron beam focussing current, loss of spark gap air, or loss of cooling water. This class of fault opens the high voltage circuit breaker and closes the high voltage grounding relays until the fault is removed. The third type of fault consists of loss of wave-guide or accelerator vacuum. In most cases this will simply be caused by the surfaces outgassing; the RF needs to be removed only long enough to permit the vacuum pumps to remove the products of the discharge and re-establish high vacuum.

Actuation of the protective equipment is indicated on the front panel of the modulator by a chain of interlock lamps. "Chain ready" information, which consists of completion of the entire interlock chain except the vacuum interlock, and "chain complete" information are available at plug 5 for remote indication. In addition, a coincidence circuit determines the existence of an RF pulse for each spark gap trigger pulse. This "misfire" information is tabulated by a mechanical register, and also is available for remote indication.

The metering on the front panel includes the Klystron filament voltage and current, the peak pulse line voltage, the HV DC voltage, the average pulse line charging current, the GL 5973 diode filament voltage, the Klystron beam focussing magnet current, the "misfire" register and the operating time meter.

The front panel controls consist of variacs for adjustment of the Klystron filament voltage, focussing current, and GL 5973 diode filament voltage.

As an aid to rapid maintenance, the following signals are available for oscilloscope observation: Klystron beam voltage and current, pulse line output voltage and current and pulse line charging voltage.

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The spark gap pulser, which is of conventional design, employs a Phillips 5C22. This chassis also contains the coincidence circuit which determines whether or not an RF pulse exists for each trigger pulse. Briefly, the circuit operates in the following way: the negative envelope of the RF pulse is obtained by means of a crystal diode and added to an attenuated sample of the trigger pulse which has been delayed a half microsecond. The trigger sample amplitude is adjusted to be equal to that of the RF envelope so that the sum of the two is zero. If the RF envelope is absent, the sum is positive and triggers the univibrator which actuates RE 1, and, by means of its contacts, transmits the information externally.

The beam focussing power supply uses silicon diodes in a six phase star circuit. The ripple in the focussing magnetic field is, therefore, synchronized with either the 360 cps of 60 cps pulsing rate.

The modulator high voltage cable is permanently attached to the modulator cubicle and terminates in a high voltage plug. This plug is mechanically interlocked with the disconnect switch so that it cannot be removed without first removing the modulator HV interlock key and opening the disconnect switch.

d. Mechanical Design of the Modulator - Drawing D-8

The dimensions of the cubicle are four by five by six feet high. The lower two and a half feet of the cubicle is an insulating liquid tank for the high voltage components. The upper three and a half feet is built in the style of standard relay racks and accommodates standard 19 inch panels. The meter panels, interlock lamp panels, pulser, focussing power supply, variac panels, and overload panel are built in the same manner as they would be for ordinary relay racks. The front panel contains an interlocked door for quick access to the spark gap for routine servicing.

Installation or removal of a cubicle requires connection of two electrical plugs, i.e. the high voltage cable and the multiconductor cable, the microwave plumbing, the cooling water, and the spark gap air.

The modulator cubicle is supported on rails mounted on a stand to facilitate handling from the transporting car.

The stand also protects the cubicle from water in case of an accident with the water cooling system. Under cubicle installation the water and air connections, filters, flow switches and flow indicators, and air adjustable support for the output waveguide are included.

e. High Voltage Power Supplies

Each 250 foot sector of the machine requires a 225 kw DC power supply to charge the pulse lines of the Klystron modulators. During Stage I the rectifier transformers would be connected delta-delta and the power supply would provide 9 kv @ 25 amperes DC. During Stage II the transformer would be connected delta-wye and the power supply would provide 15.5 kv @ 14.4 amperes DC. Stanford has selected the repetition rate and number of Klystron modulators to make the most efficient use of these power supplies in each stage of the program.

The AC input to the power supply is from a three phase 480 volt line. Each power supply contains its own disconnect switch, contactor and 15% buck-or-boost induction regulator. The inrush current is reduced by means of step-start resistors, but even so, the forty power supplies should be brought on the line in sequence. Each power supply is self-protecting and employs standard interlocks and time delays. The interlock chain lamps, instruments and remote control circuits are brought to terminal strips so that control and indication can be made available at the sector console.

3. Master RF Drive and Trigger System (Drawing D-4)

a. General Description

This system would be built in duplicate in order to reduce "outage" because failure of any of these components removes exitation to a significant fraction of the accelerator. Thermal variation of the phase velocity in the master RF and trigger lines can be kept to a minimum by using the TEM mode in coaxial lines with strofoam dielectric. The attenuation in this type of line is of the order of one db per hundred feet. Booster amplifiers will be required every 2500 feet in each of these lines. Transfer from one line to the other is accomplished by coax relays operated from the main control room.

The trigger pulse for each sector should be bridged off of the master trigger coax by means of a non-inductive isolating resistor. The value of this resistor will be different for each sector in order to compensate for the attenuation along the coaxial line. The trigger cable from each bridging junction of the master trigger coax to the sector pulser can be RG 8/U. Precise timing of the sector pulsers can be achieved by suitable choice of the length of this cable.

Phase of the RF pulse is accomplished by adjustment of the phase shifter in the input guide of the sector RF booster amplifier.

b. Master Oscillator

The master oscillator consists of a temperature controlled crystal oscillator operating at a relatively low frequency -- 11.73 mc., with five frequency triples producing 2850 mc. The final amplifier of the master oscillator chassis would be a 50 watt Klystron. The crystal oscillator and the frequency multipliers would operate CW in order to achieve a high degree of frequency stability.

c. Master Pulser

The master pulser is triggered by the 60 cps line. It produces a 15 kv. one microsecond pulse at a repetition rate of 360 pps for Stage I or 60 pps for Stage II. The jitter time of the pulse must be less that 0.1 microsecond. It should have an auxiliary output, isolated from the main output, which can be used to drive experimental equipment in the counting area.

d. RF Booster Amplifiers

The RF booster amplifier modulators are essentially the same as the main modulators except that Varian VA87C tubes are used in the place of the Stanford Klystrons. Since the beam voltage is only 90 kv a lower ratio pulse transformer (7:1) and a higher impedance pulse line are required. The pulse length should be somewhat longer than that of the final amplifier to reduce the timing accuracy requirements.

4. Sector RF Drive and Trigger System - Drawing D-4

a. General Description

The sector driver amplifier excites a terminated waveguide from which the Klystron final amplifiers receive their input signal. The signal is extracted by means of four hole directional couplers which provide a high degree of discrimination against the phase error produced by any reflected wave in the drive guide. The coupling factor of the directional couplers vary with their position in order to compensate for attenuation in the guide and thus provide the same amount of RF power (10 kw) for each final amplifier. This is further reduced to the proper drive level by adjustment of the attenuator in the input of each final amplifier.

The sector pulser produces two output pulses -- one for driving all of the final amplifier pulsers of the sector and the other delayed about 100 microseconds for pulsing any Klystron cubicle between beam pulses for test purposes. The RF drive for the cubicle being tested would be obtained from a portable signal generator.

In Stage I each sector uses only 12 Klystron final amplifiers; thus each drives two sections of the accelerator. The phase adjustment for the second sector is made by means of a "U" section of guide. "U" sections of the proper length with shims of the proper thickness would be selected to give the desired phase shift. A phase shifter capable of operating at this power level has been developed at Stanford and could be used in place of the "U" section if desired.

In Stage II eleven more Klystron cubicles are added to each sector so that each 10 ft. section of accelerator has its own Klystron final amplifier. The master pulser repetition rate is changed from 360 to 60 pps and the rectifier transformers of the high voltage power supplies are changed from delta-delta to delta-wye. The high voltage power requirements for Stage II are, therefore, almost the same as Stage I.

b. Sector Pulser

The sector pulser is much like the master pulser so far as pulse height, duration and rise and fall time are concerned. However, in addition to the main driving pulse, there is a delayed pulse required which can be used to test a Klystron cubicle by pulsing it out of step with the beam.

5. Injection and Phase Adjustment

a. Phase Adjusting Procedure

With the sector isolated and the local inflector and deflecting magnet in use, the Klystron input phase shifters would be adjusted for maximum beam energy. The probes in the slotted lines would then be set and locked at their null positions. Subsequent phase adjustments would then be made without interrupting the main beam by observing the indicating meters at each cubicle. This would be done with adjacent cubicles driven by a portable RF signal generator. For a complete tuning adjacent cubicles would be compared, working both ways from the center to the ends of the sector. If at any time there was a question of the accuracy of the meters, the inflector-deflector system could be used. The beam could not be accelerated during this check because of the disturbance caused by the deflecting magnet.

b. Phase Meters - Drawing D-6

The phase angle between theRF of adjacent accelerator sections can be measured by observing the locations of a null in a standing wave formed from samples of the two signals. The samples are obtained by means of directional couplers and the unused end of each coupler is terminated in the characteristic impedance of the guide in order to minimize reflections which would interfere with the measurement. The null could be located by means of a probe and a crystal in a slotted section of the guide. The accuracy of three electrical degrees requires that they be mechanically resetable to about 0.030 inches.

c. Electron Gun and Power Supplies

The main electron gun at the starting end of the machine is identical to that now in use on the existing Stanford Linear Accelerators. Each 250 ft. sector, except the last, also has an identical gun for injecting a test beam into the next adjacent sector.

The power supply for the main electron gun and its spare would be mounted in adjacent racks for quick changeover in the event of a component failure. This power supply would use a pulse line for the anode supply and an emission current regulator for the filament. The latter insures that the filament is always operated at the minimum temperature necessary to produce the required emission current.

The power supplies for the sector electron guns do not have to be so elaborate since they are essentially a test facility only used occasionally. The high voltage would be produced by a pulse transformer driven by a thyratron pulser -- much the same as the pulse booster amplifiers. The filament voltage would not be regulated but simply obtained from a filament transformer and variac.

d. Sector Inflector - Drawing D-12

This device consists of an electron gun identical to that at the starting end of the accelerator and an electrostatic deflector which is arranged to clear the main beam. Both the injector and inflector are pulsed together, the former at 80 KV and the latter at a lower voltage. The electric field required is small. No difficulty should occur with sparking.

e. Sector Deflecting Magnet - Drawing D-12

These are conventional direct current bending magnets requiring 12 KW of DC power. This would be supplied by a magnetic amplifier regulated to 0.1%. The ripple in the magnetic field would be removed by eddy current shielding. The magnet is mounted on a truck to permit moving it away from the beam during normal operation so that its residual field will not disturb the beam.

6. Beam Switchyard Magnets

This includes the 3 bending and 3 quadrupole magnets to produce the two left hand deflected beams. We reviewed the design of these magnets and their estimated cost and our figures are in close agreement with those in the Proposal. Each magnet will be mounted on an adjustable support. The magnets will be installed through the tunnels from the end station. The magnets for the right hand deflected beam are not included as they are not now considered a part of either Stage I or Stage II.

7. Focussing, Degaussing and Steering System

A focussing coil requiring not over 200 watts is assumed for each sector.

Four degaussing conductors of No. 10 wire in protecting conduits as shown on Drawing D-11 run the length of the tube. They require approximately 4 KW total and would be expected to cancel 99% of the earth's field.

A pair of steering magnets requiring not over 200 watts is provided at each sector with independent power supplies regulated to 0.01%.

8. Vacuum System

The vacuum system layout and dimensions follow very closely those described in the Proposal. The only important changes are the addition of roughing pumps and an additional finishing manifold for the waveguide vacuum system. The roughing pumps have been sized to pump the manifolds down in the order of half an hour which we feel is a reasonable time. The waveguide finishing manifold is provided to permit pumping a window section to a vacuum of the order of 10^{-4} mm before connecting it to the holding manifold where the remaining gas would raise the pressure on all the windows of the sector. This is based on the assumption that the best possible vacuum should be maintained between the windows at all times that the RF power is on to reduce the chance of window failure.

9. Controls and Instrumentation

The estimate included for controls and instrumentation is based upon the requirements as outlined in the Stanford Proposal with but few exceptions. The main control room would include about 4000 lights, 3500 controls and 300 meters and oscilloscopes.

a. Type of Control

The capacitance between adjacent control wires, approximately 1 Mfd per mile, dictates that direct current be used to eliminate cross talk between long distance circuits. The controls would be carried in pairs of twisted #22 wire similar to telephone communication cables. The preferred voltage is (-) 48 volts DC.

b. Control Multiplexing

The average cost of one pair of #22 AWG long-distance control wire, plus a control relay will run about $90 per circuit not including the right-of-way. Therefore, it is essential to multiplex the use of the wires where this can be done reliably and where the cost of the multiplexing is less that $90. 00 per pair of wires saved.

Typical type of multiplexed information included in the report is:

Off, flashed light for warning, steady light to show normal operation.

Forward or reversed polarity on the wire for two functions such as up and down control with diode and relay separation at the equipment end of the circuit.

Forward or reversed polarity plus diodes and lights can be used for two light indications such as on the vacuum valve position indication.

c. Special Monitoring

It will be vitally important to display the accelerator operation as simply as possible to aid the operator to see the relative operation of the machine at a glance. A scanning scheme for this purpose has been included as shown on Drawing 200-19-D9. It allows the sector operator to check the sector under test and it also allows the main control room operator to see the total accelerator operation on one oscilloscope and at the same time allowing for detailed observance of each sector if desired. A high-speed monitoring circuit covering the length of the machine is included that will allow the outputs of various non-destructive beam monitoring amplifiers from the sectors to be delayed and displayed in sequence on one sweep of an oscilloscope thus giving a good display of the beam pulse as it proceeds down the tube.

d. Remote Instrument Scale Changing

It is planned that all remote reading instruments such as Ion Gauges, and radiation gauges be self-balancing and stable. No remote scale changing controls are provided, since it would add unnecessarily to the cost of the instrumentation.

e. Communication

The area paging system will be divided so that individual areas such as the end station, injector, Klystron tunnel and accelerator tunnel may be paged without disturbing the rest of the areas.

Eleven station sound powered phones with ringing circuits will be used to establish the private line communication system. Trunk lines would be set up to the various sectors from the master control room.

4 Instruments in the M.C.R.
1 Instrument at each Sector Control Room
1 Instrument for every 2 modulators
10 Instruments at beam station and injector.

10. Tools and Test Equipment

Electronic and electrical test instruments, vacuum gauges and leak detectors and mechanical alignment fixtures are included under this heading. Test stations for the Klystron cubicles and power RF testing are not covered here but are included in the accelerator prototype estimate.

11. Accelerator Engineering Design, Construction, Supervision and Check-out

Engineering and technical personnel required for design, supervision of construction and adjustment and check-out of the accelerator equipment prior to the operation of the machine as a whole has been estimated.

The largest groups comprise those working on the RF system and those on the vacuum system. The estimate of effort is as follows:

	Man Months
Electrical and RF	794
Mechanical and Vacuum	727
Other	907
	2,428

APPENDIX II

INTRODUCTION

Stanford University proposes to construct a two-mile linear electron accelerator at a site adjacent to the University Campus on Stanford-owned land. The Stanford proposal is contained in a report prepared by the University staff titled "Proposal for a Two Mile Linear Electron Accelerator", dated April, 1957.

The United States Atomic Energy Commission has retained William M. Brobeck and Associates to review the Stanford Proposal and the estimates therein. Brobeck, in turn, has retained Kaiser Engineers as a subcontractor to review and to prepare cost estimates on certain elements of the work. This report summarizes the work performed by Kaiser during the period June 5, 1958 to July 3, 1958.

SCOPE OF WORK

The scope of Kaiser's work consists of developing the required information, drawings, and engineering to provide estimates of cost for the following elements:

A. Tunnel Construction Estimates

1. Surveys and borings
2. Engineering design
3. Drilling - Klystron tunnel, accelerator tunnel, cross drifts at 250-foot intervals, tubes at 9-foot intervals, elevator shafts, utility shafts, ventilation shafts, substation vaults
4. Page Mill crossing fill and earth shielding
5. End station cut and fill
6. Concrete and steel work associated with the above, including drainage
7. End station earth and concrete shielding

B. Tunnel and End Station Estimates

1. Air conditioning - ventilation, air cooling, dehumidifying, heating
2. Handling equipment - cranes in accelerator tunnel and cross drifts, cranes in work areas, Klystron cubicle handling, miscellaneous tunnel handling, cranes at end station, cranes at tunnel entrances, elevators

3. Lighting and plug-in power outlets

4. Equipment foundations

5. Sanitary facilities

6. Fire safety system, alarms and extinguishing systems

7. Ground water drainage

8. Public address systems

C. Site, Tunnel and End Station Utilities Estimates

1. Electrical ac power - PG&E feeder line, main station, substation. Including to local connect boxes at Klystron cubicle, elevators, cranes, utilities, pumps, blowers, lighting and power panels, etc., in tunnel and end station and through local building or utility substation for site.

2. Standby emergency power where required - ventilation, research areas, cooling water

3. DC power distribution between power supply and load

4. Utility piping systems site, tunnel and end station

   a. Domestic water

   b. High pressure water and tanks

   c. Treated water

   d. Compressed air including compressors

   e. Gas including standby storage

   f. Cooling water and towers including manifolds to individual Klystron cubicles and 10-foot accelerator sections.

D. Building Estimates

All buildings - office, research, end station, shaft covers, warehouses, Klystron factory, electroforming, machine shop, miscellaneous shops, electrical, plumbing, paint, carpentry, garages, etc. Including all normal building equipment and utilities, i.e., heating, ventilating, elevators, water, sanitary facilities, fire protection sprinklers, built-in benches, hoods and utilities but not technical or movable equipment such as research instruments, shop tools, electroforming equipment, furniture, etc.

E. Site Estimates

All site work including but not limited to drainage, grading, paving, fences, landscaping.

LIST OF DRAWINGS

The following drawings have been prepared to assist in preparation of cost estimates and are included herein.

Title	Drawing No.
End Area Arrangement Plan	101-C
Plan and Profile	102-C
Tunnel Plans and Sections	101-S
End Station Details	102-S
Tunnel Details	103-S
Electrical Power Single Line Diagram	101-E
Tunnel Wiring Scheme	102-E
Power Layout Outside Tunnel	103-E
Compressed Air and Water Flow Diagram	101-P
Tunnel Piping Plan	102-P
Tunnel Piping Details	103-P

BASIS FOR DESIGN

Designs are based on criteria stated in the Stanford Proposal, modified and supplemented where necessary by information obtained from Brobeck, from Stanford University, from serving utilities and from reports of the Utah Construction Co. and Bechtel Corporation which were used in preparation of the Stanford report. Modifications are indicated by asterisk.

A. Functional Requirements

The accelerator is housed in a 10-foot diameter tunnel separated from an equipment tunnel by 35 ft of earth. The tunnels terminate in a beam switchyard followed by an end station structure in the target area.

The tunnels are divided into forty (40) 250-foot sectors.

Location, elevation and cross section of the tunnels are as specified in the Stanford Proposal. Alcoves are added as shown for electrical equipment.*

B. Basic Utility Requirements

1. Klystron Cubicle - 23 per 250' sector

10 amps 115v 1 phase 60 cycle ac - Klystron Auxiliaries
10 amps 115v 1 phase 60 cycle ac - Klystron Heaters
0.6 amps 14 kv (22 kv insulation) from hv bus
2 kw 208v 3 phase for focusing magnet rectifiers from sector load center
50 cfm compressed air supply and return - 5 psi drop through load, clean dry air - 10% makeup
(5 gpm Stage I. 3.5 gpm Stage II) Demineralized water 50 psi supply, 35 psi return. Supply temperature regulated between 70°F and 90°F. Protection against pressure above 60 psig, 10 kw heat input to water.
1,500 watts heat loss to surrounding air

2. Accelerator Tube - 23 sections per 250' sector

Ten (10) gpm demineralized water. Supply regulated to 2°F range at tube inlet. Supply temperature adjustable 92°F to 110°F. A sector circulating pump, 7 1/2 hp and circulating piping is provided. Makeup and return are through Klystron water headers.

3. Sector Vacuum Pump - Every 250 feet

Pump Exhaust - 100 cfm
6 kw 60 cycle 230v ac power
4 gpm demineralized water - 60°F to 80°F, 50 psi supply, 35 psi return.

4. Sector Roughing Pump - 15 hp

5. Sector Load Center - Every 250 feet

Focusing coil supply - 46 kw 3 phase ac output
Main dc rectifier - 250 kw 3 phase 4 kv ac input, 14 kv output, to hv bus
Klystron heater power supply 25 kw 115v ac output
Lighting outlets - 5 kw
Inflector deflector system - 20 kw
Control power 20 kw, 1 phase ac
Test equipment 20 kw, 1 phase ac
Power for monorail crane system
Convenience outlets - 10 kw
Klystron booster - 5 kw

6. Injector Station

25 kw, 1 phase 230v ac

7. Beam Switchyard

Miscellaneous loads - 50 kw 1 phase ac
Magnet motor generators
3 - 600 kw 600v dc output
2 - 200 kw 250v dc output
1 - 50 kw 250v dc output
225 gpm demineralized water 60 psi supply, 30 psi return, 2,250 kw heat input, maximum temperature 140°F
50 gpm demineralized water 60 psi supply, 35 psi return, 50 kw input, maximum temperature 100°F
Vacuum pumps
30 kw 60 cycle 230v ac power
20 gpm demineralized water, 60°F to 80°F, 50 psi supply, 35 psi return

8. End Station

2500 kw miscellaneous experimental power
400 gpm demineralized water, 60 psi supply, 30 psi return, 2000 kw heat input, maximum temperature 140°F
Power for four (4) 100-ton cranes with 15-ton auxiliary hoists
Vacuum pumps
90 kw 60 cycle 230v ac power
60 gpm demineralized water, 60°F to 80°F, 50 psi supply 35 psi return
10,000 kva dc power supply to End Station

C. Tunnels

1. Functional Requirements

Tunnel sections and elevations are as shown in the Stanford Proposal. No investigation of alternate types of construction, of location or of elevation has been made.

Cross tunnels are located at 250-foot intervals between tunnels for access from the Klystron tunnel to the Accelerator tunnel. There are twenty-three (23) 8-inch diameter wave guide tubes on 9-foot centers per 250-foot sector.

An access shaft is provided at station zero for construction purposes and for escape during operation. A permanent elevator is provided in this shaft. An air supply shaft is provided at station 54+00 for operating use.

Side vaults are provided for electrical gear along the tunnel.

The above facilities are shown on attached Drawings 102-C and 101-S.

2. Geology

The tunnels are located in the foothills of the Coast range on Stanford University land adjacent to the campus. An abandoned rock quarry exists to the west of the tunnel site. Six (6) exploratory borings were made in the general area by the Utah Construction Co. for other purposes. None of these borings was carried to tunnel depth.

The geology of the area is determined from surface indications and from examination of the logs of these borings.

A review was made of geological data used by the Utah Construction Co. and by Bechtel Corporation. Independent geological determinations were made by Kaiser Engineers staff geologists after examination of this data and of the site.

The conclusions are as follows:

General

The tunnels can be constructed at the designated site.

Underground Water

Only minor amounts of subsurface water are indicated at a point ± 3,000 ft from the northwest end at the fault contact

of sandstone and basalt. No flooding is expected. Area expected to produce small, steady runs and heavy dripping until drained.

Faulted Areas

Two minor faults are indicated, at ± 3,000 ft and ± 8,900 ft from the northwest end. At ± 3,000 ft the movement is a reverse dip-slip fault along the contact wherein the overlying massive sandstone has ridden up dip on the basalt, with little shearing or fracturing of either. At ± 8,900 ft the fault is expected to occur in the deep end of the open cut or close to the portal and to be accompanied by minor shearing and crumpling of the basalt and sandstone. Neither fault is expected to result in difficulty to routine tunnel or open cut driving.

Detailed Tunnel

Stations N.W. End = 0	Linear Dist.	Type Opening or Work	Material
0		Shaft	Sandy Shale & Massive Medium Hard Sandstone
0 - 3,000'	3,000'	Tunnel	Massive Medium Hard, Poorly Cemented Sandstone
0 - 3,000'		Tunnel	Wet Fault Contact @ ± 3,000' Easy drilling, poor breaking
3,000'-3,750'	750'	Tunnel	Basalt & Volcanic Breccia Very hard drilling, good breaking
3,750'-8,050'	4,300'	Tunnel	Minor Interbeds - Shale & Sandstone Major Massive Poorly Cemented Sandstone
@ ± 5,400'		Shaft	Major Massive Poorly Cemented Sandstone
3,750'-8,050'		Tunnel	Interbeds - Shale & Sandstone and Massive Poorly Cemented Sandstone Easy drilling, poor breaking
8,050'-8,850'	800'	Tunnel	Basalt & Volcanic Breccia Very hard drilling, good breaking
8,850'-9,450'	600'	Open Cut & Fill	Volcanic Breccia & Basalt
9,450'-9,900'	450'	Tunnel	Volcanic Breccia Hard difficult drilling, good breaking
9,900-10,000'	100'	Open Cut	Volcania Breccia & Sandstone
TOTALS	10,000'		

3. Design

Tunnel designs and estimates are based on the geological conclusions indicated above. The following criteria are used for tunnel design:

Supported Length: 100%
Tunnel Lining - 100% of tunnel as indicated on attached drawings.

Estimates of cost are based on the anticipated progress and costs for tunneling in each of the several formations encountered. Tunnel construction is estimated between Station 0 and Station 88 with open cut construction anticipated from Station 88 to Station 100.

4. Utilities

a. Drainage - Tunnel drainage is accomplished through gravity drains to vertical sump pumps on 1000-foot centers discharging outside of the tunnels.

b. Ventilation - Tunnel ventilation is provided for a working tunnel population of 200 people. Criteria are as follows:

(1) Outside air (summer) 90°F - db & 70°F - wb
(2) Required atmosphere in tunnel 74°F - db & 45% rh (60°F - wb)
(3) 100 cfm/man @ 200 men
(4) Minimum 1/3 air change/hour in tunnel
(5) 50 fpm maximum and 25 fpm minimum air velocity in tunnel
(6) Fresh air introduced from central shaft must be dust-free and 47° dew point to pick up moisture in tunnel
(7) Tunnel heat is removed by chilled water units along the tunnel ceiling.

c. Design Data

(1) Refrigeration Required: 654 tons (for 7,832,000 BTU/hr)
(2) Chilled Water Requirements: 1,370 gpm to tunnel

d. Sanitary Facilities - Sanitary facilities to support 200 men are located along the tunnel.

e. Domestic Water - Domestic water is provided in the tunnel.

f. Lighting - Approximately 45 foot-candles of lighting is provided.

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g. Fire Protection - Fire protection is provided by location of hand extinguishers located at 50-foot intervals along the Klystron tunnel. A truck mounted, battery operated fire truck is located outside of the tunnel for dispatch to any point in case of emergency. "Askarel" or other nonflammable insulating liquid will be used for all liquid insulating requirements.

h. Transportation and Material Handling - Transportation in the tunnel is provided by six (6) 30-foot battery operated rail cars. Cars and trailers are equipped to handle all routine maintenance in the tunnel and to transport and store maintenance materials. Crossovers between tracks are provided every 250 feet to permit passing during work periods. Booms are provided on the cars for ready removal and replacement of operating equipment.

D. End Station Area

The end station area and the beam switchyard are graded as shown on the attached Drawing 101-C.

The beam switchyard is constructed in open cut and back-filled to provide 35 feet of cover for shielding.

The following facilities are provided:

1. Beam Switchyard

The accelerator tunnel is continued to two separate tunnels for entry to separate target areas in the end station, with provision for two future extraction points as shown on Drawing 101-C.

Magnet removal is through the end station building by flat car from tunnels to pickup with end station building cranes.

2. Structures

Structures are designed in accordance with the Uniform Building Code, Pacific Coast Edition 1958. Maximum foundation pressure 3 Kips/sq ft.

The following structures are provided:

Structure	Size	Type	Special Requirements
a. End Station Main Bldg.	200,000 sq ft 98 ft high	Steel frame, corr. iron, ins. siding	4-100/15t cranes Floor Load - 2.5 Kips/sq ft

Structure		Size	Type	Special Requirements
b. End Station Aux. Bldg.				2 Stories
Office	5,000		Steel frame, corr. iron ins. siding	Research Lab R.F. Rm. air-conditioned 6.2 tons required
Observation	8,000			
Storage	3,000			
Machine Shop	9,000			
Research Lab				
Physics	10,000			
Electronics	6,000	41,000 sq ft		
c. General Services			Concrete block	
Shops	8,000			
Stores & Rec.	5,000			
Garage	1,000	14,000 sq ft		
d. Klystron Factory			Concrete block	
Storage	2,500			Clean room. Air-conditioned 1500 sq ft-4.8t Refrig.
Shops	20,000			
Laboratory	7,500			
Office	3,000			
Accelerator Proto Type Lab	13,500	46,500 sq ft		
e. Accelerator Storage & Shops		46,000 sq ft	Concrete block	Electroforming Shop Air-conditioned 2,500 sq ft, 8.5 t air-conditioning
f. Administration Bldg.			Concrete block	2 Stories
Administration	16,000			
Engr. & Science	16,000	32,000 sq ft		
g. Accelerator Control Rm.		5,000 sq ft	Concrete block	Pressurized
h. Pump Station and Demineralizer		1,000 sq ft	Concrete block	
i. Compressor Building		2,800 sq ft	Concrete block	
j. Ventilation Equip. Bldg. (at Station 54+00)		1,000 sq ft	Concrete block	

3. Parking and storage areas are provided in the end station area as follows:

End Station Outside Storage	20,000 sq ft
Corporation Yard	5,000 sq ft
Klystron Factory Outside Storage	6,000 sq ft
Accelerator Outside Storage	10,000 sq ft
Main Parking Area	60,000 sq ft
Nitrogen Storage and Handling	1,900 sq ft

4. Additional facilities in the end station area are:

2.4 kv Substation	4,600 sq ft
Main Substation Area	14,400 sq ft
Cooling Tower Cold Well for Compressor Cooling	100 sq ft
MG Sets and dc Switchgear	3,400 sq ft
Cooling Tower, Heat Exchangers and Hotwell	

5. Shielding

Ordinary concrete shielding blocks for end station target areas are provided as shown on Drawing 102-S.

Beam switchyard shielding is as shown on Drawing 101-C.

E. Electrical Distribution

The electrical distribution system is delineated on the following drawings:

Power Distribution Single Line Diagram	101-E
Tunnel Wiring Scheme	102-E
Power Layout Outside Tunnel	103-E

These drawings cannot be considered to be a final and definitive design. They represent a reasonable solution for scoping and estimating purposes.

The system is described as follows:

1. Main power supply is from a single 110 kv line from the PG&E Monte Vista substation.*

2. The main substation includes 110 kv disconnects ahead of the transformers, two transformers 15/20/25 mva 110 kv/13.8 kv, necessary 110 kv equipment, bus connection to indoor 13.8 kv, 500 mva, and switchgear consisting of 18 breakers 1200 amps each.

3. The main substation feeds the tunnel by means of two 13.8 kv substation A and B, each taking care of 5 load centers comprising 5,000 ft of tunnel.

   The entire system is laid out with double busses and double feeders, the latter capable of supplying 100% of the load of the sub unit.

4. The load centers in the tunnel consist each of two 1,000 kva, 13.8 kv/480-277v transformers, main tie- and feeder-breakers, as shown on Drawing 101-E.

5. All motors 300 hp and larger (with the exception of two remote 400 hp motors) are connected to 2,400v. There are two transformers 2,500 kva, 13.8/2.4 kv supplying these motors. Transformers are connected to a 5 kv switchgear which is tied to the emergency power supply system. The latter consists of two diesel-driven generators of 1,000 kva each. Outside of the tunnel is an additional emg substation of 200 kva for fire pumps, battery chargers, etc.

6. There are two dc systems--one 600v and one 250v.

7. There is a complete dc control system as per Drawing 104-E.

8. There are 12 motor control centers 480/277 volt with approximately 20 combination starters size 1 for a total of 200 hp and 2 mcc 480/277v with approximately 20 combination starters size 1 and 10 combination starters size 3 for a total of 200 hp.

9. There are approximately 50 lighting panels outside of the tunnel for a total of 1,500 kva lighting load. The lighting intensity is figured at 4 w/sq ft, corresponding to approximately 45 foot-candles.

10. There is provision for an extensive grounding system.

11. Communication, intercom, and alarm systems are provided.

12. For supervision of the power system only an annunciation system of 3 x 32 drops with 2 horns is provided.

13. The 480/277v supply to the Klystron auxiliaries in the tunnel is shown in detail on Drawings 101-E and 102-E.

14. A separate item is the future supply of 10,000 kva to the end station for dc power. This is shown dotted on Drawings 101-E and 103-E. Allowance is made for this supply and for conversion to dc followed by distribution in the end house.

The load, compared with the original as given in the Stanford Proposal, is:

Item	Connected Load (kva) 6/21/58	Stanford Proposal	Assumed Simultaneous Load (kva)
Tunnel	21,500	15,010	18,600
Beam Switchyard	3,650	2,800	2,000
End Station	3,900	4,300	3,300
End Station Future	10,000	-	10,000
Prototype	2,250	2,250	2,250
Administration, Shops, Etc.	3,170	2,810	3,170
Outdoors	-	500	-
Air Conditioning on Top of Shaft	1,000	-	1,000
Pumps and Cooling Fans	3,690	-	2,750
Compressors and Refrigeration	4,120	-	4,120
TOTAL	53,280	27,670	47,790

F. Water Supply

890 gpm of raw water is supplied from the Hetch Hetchy Line at Page Mill Road and Foothill at a pressure of 100 psig. This supply is apportioned to domestic, demineralized water system makeup and to cooling tower makeup as shown on Drawing 101-P.

The domestic supply does not require further treatment. Domestic water distribution is through cast iron mains in the end station area and steel pipe in the tunnel.

The demineralized cooling water system cooling is accomplished in a shell and tube heat exchanger with system makeup through a 245 gpm demineralizer. Rubber lined pipes and fittings are used for sizes 2" and above, plastic pipe and fittings under 2".

G. Compressed Air

Fifty (50) cfm of compressed air is supplied to each group of three Klystron tubes through a closed system for compressing 17,000 cfm with 10% makeup as shown on Drawing 101-P. All compressed air piping is steel.

H. Vacuum Pump Piping

Vacuum pump cooling water and exhaust piping is mild steel.

I. Fire Protection

A fire protection loop and 150,000-gal storage tank will be provided for end area and administrative area fire protection. Cast iron, steel or transite pipe is used. Facilities are shown on Drawing 101-C.

Sprinklers are provided in:

End Station (2-story building)
General Services Building
Klystron Factory
Accelerator Storage and Shops
Administration Building

J. Natural Gas

Natural gas distribution is shown on Drawing 101-C.

K. Sewage

Sanitary sewage is discharged to the City of Palo Alto system at Page Mill Road and Foothill. The sanitary sewage system is shown on Drawing 101-C. Sewage from the tunnel is pumped into this system.

L. Nitrogen

Nitrogen storage and handling facilities are located outside the tunnel. Nitrogen is brought to service points in the tunnel on service cars as required.

SITE INVESTIGATIONS

Additional site investigation is required prior to detailed design. The following is recommended as the minimum requirement:

A. Tunnel Exploration

Seven (7) NX core holes to tunnel invert are recommended along the tunnel axis line to check projected structure and physical character of rock.

B. Foundation Investigation

1. End Station Structure

Four (4) borings to rock are recommended under the main end station structure.

Ten (10) additional borings to rock are recommended in the end station and administrative areas.

BASIS FOR ESTIMATE

The attached estimate of cost is based on the designs and on the requirements described in this report and on the attached drawings.

All costs are based on current prices for labor and material in the Palo Alto area.

Escalation is shown as a line item following the estimate and is computed on the basis of an equal declining balance over the full construction period with construction estimated to start July 1, 1959. Annual escalation is estimated to be 5.6%. Contingency is taken at 15% of total estimated cost.

An attempt is made to construct the estimate in the same form as the Stanford estimate for ready comparison. This has not been possible in all cases due to differences in maintaining cost records for construction labor and overhead. Unit costs as expressed in this estimate generally include those fringe and overhead costs normally included in contractor's cost data; the Stanford estimate separates many of these costs into administrative and overhead items.

APPENDIX III

PROTOTYPE FACILITY

The prototype facility estimated provides for development of the Klystron tubes and all critical components of the RF vacuum and control system and for life testing the Klystron tubes as described in Appendix IV. The facility is assumed to consist of the following three units:

1. The Prototype Accelerator 160 feet long powered by a maximum of 13 Klystrons.

2. Ten component test cells each capable of testing one Klystron with a ten foot section of accelerator tube.

3. Ten Klystron life test stands.

The length of the prototype accelerator is chosen to correspond to one-half section with the addition of one section for injection. It would be provided with vacuum pumps at one end sized to give the same pumping conditions that would exist on the main machine. The cubicle installation would be identical to that on the main machine with waveguides of the same lengths and geometry. DC power capacity equivalent to two of the main accelerator sectors would be provided to permit operation at maximum power with a high repetition rate. Inflection, deflection steering, degaussing and focussing equipment identical to the main machine are provided for test and development purposes. The control problems of the Two-Mile machine would be simulated by coiled cables and delay lines to permit developing and checking the long lines required. The prototype would be very valuable to check the full-scale design before the start of full-scale production.

The prototype machine would be enclosed in a shield of removable concrete blocks three feet on all sides except where it was penetrated by the waveguides where it would be six feet. The space inside the shield would have the width and clear height of the accelerator tunnel.

The ten component test cells would be similar to the prototype machine in shielding and power capacity but would operate as individual units. Each could be used for testing a separate component if necessary. They would be provided with about double the power per Klystron available on the main machine when operated in Stage I.

The ten tube test stands would be used for life testing Klystron tubes and would operate long hours at high power without changes. They would test improvements which have received preliminary testing in the component test cells and on which reliability data was to be obtained. For this purpose, they should be kept separate from the more experimental group of tubes powering the test cells. This tube life test facility is described further in Appendix IV.

APPENDIX IV

SECTION A

KLYSTRON PRODUCTION STANFORD ACCELERATOR PROPOSAL

1. Introduction

Power for acceleration of the electron beam is furnished by a large number of independent RF amplifiers, operating at a uniform frequency, 2856 MC/sec. The peak output power rating, currently 17 megawatts and expected to be 22 megawatts eventually, is considerably higher, by a factor of three to five, than can be obtained from any commercially available amplifier tubes. To meet this requirement, Stanford has designed a high power Klystron, the Mark I, which has been operated successfully on the Mark II, Mark III, and Mark IV Accelerators for several years. This tube is, however, normally continuously pumped to avoid the serious limitation in life imposed by the rapid rate of failure of output windows which has been experienced up to this time.

It is proposed to develop a sealed-off Klystron similar to the Mark I in power capability for installation in the proposed Two-Mile Linear Accelerator. This study attempts to estimate the cost of tube development, the cost of manufacturing facilities to produce such a tube, the cost of the tube, and the portion of accelerator operating cost arising from tube replacements.

2. Summary and Conclusions

a. Existing data describes the operation of the Mark I Klystron and the output window only at the peak power level of 17 megawatts, a repetition rate of 60 cycles per second, and pulse length of 2 microseconds. No data exists on its operation under other values of these parameters. Under these conditions, the life of the window, independent of the life of the tube, is described by the function:

$$Pw = e^{-.0005234\,t}$$

Where Pw = proportion surviving
e = 2.718
t = operating time in hours

The life of the tube, independent of the window, is described by a normal, or Gaussian, distribution, having a mean life of 1400 hours and a standard deviation of 500 hours. Tube life, thus described, is essentially cathode life.

b. The distribution of window life and tube life appear to be quite independent, and in a sealed-off tube, in which a failure of either window or cathode terminates the life of the tube, the probability of survival will be the product of the probabilities of window survival and of cathode survival.

c. Data on the effect of variation in operating parameters of peak power, repetition rate, pulse length, temperature, and shelf storage time is needed in order to evaluate the probable performance and cost of operation of the proposed accelerator under any conditions other than the single set on which data presently exists. Such data can be secured only by the establishment of an independent Klystron development program, on a scale which is much larger than the present program.

d. With a large margin of uncertainty imposed by lack of data on the Klystron tube which is to be developed for the proposed installation, the estimated Klystron investment cost factors in the proposal are as follows:-

	Stage I	Stage II	Total
Klystron Development Cost	$1,300,000		$1,300,000
Klystron Factory Cost	1,235,000	$ 135,000	1,370,000
Klystron Production Cost	2,660,000	2,660,000	5,320,000
Total Investment	$5,195,000	$2,795,000	$7,990,000

e. With the same uncertainty, the estimated annual operating cost including overhead arising from replacement of Klystrons, is as follows:

Annual Cost, Stage I	$2,820,000
Annual Cost, Stage II	$5,640,000*

A thorough investigation should be made of the possibility of securing all Klystrons for the proposed accelerator installation and operation through commercial channels.

(*) Assumes a tube life of 2,000 hours the same as Stage I.

3. Discussion

a. Klystron Life

The Mark I Klystrons used on the present Mark III Accelerator have accumulated sufficient statistical data to permit extrapolation to probable experience in the proposed Two-Mile Accelerator. Mark I tubes differ, however, from those proposed for this use in that they are continuously pumped, while the proposed tube is to be sealed-off. In order to estimate the probable experience with the sealed-off tube, it is necessary to calculate the probable frequency distribution of failures, taking into account the two chief sources of failure, which are independent of each other. These two sources of failure are output windows and cathodes. Some failures do occur for other reasons but they are comparatively few in number.

The Stanford experience with output windows from 1954 through 1957 on the Mark III Accelerator at 17 MW peak power is given in Table IV-A-1 and as a histogram in Figure IV-A-1. The number of windows tested to failure is 90 (a sample size quite adequately large to determine probable life of this particular window, a high alumina disc metalized and brazed in a cylindrical copper shell) at the 17 MW peak power level. The life curve has been plotted on a semi-log scale chart, Figure IV-A-3. The distribution is an exponential decay function in which a constant percentage of failures is experienced in each equal time interval. For this particular window, 40% fail in each 1000 hours of operation. It is convenient to express the probable life of a component, which exhibits a constant probability of failure, in terms of half-life, in this instance 1320 hours. The probability of survival is given by $P = e^{-.0005234\,t}$, where t is in hours.

An interesting feature of such a distribution in which the probability of survival is a constant is that the liklihood of survival is independent of previous history. Although large numbers fail in the first period of operation, this cannot be used as a sorting method since the same percentage of surviving windows will fail in the next equal period. This relationship holds quite exactly in the sample of 90 until less than 10% of the original sample remains, at

which point the remaining sample becomes too small to give significant results. With this in mind it becomes evident that a used window, regardless of its length of service, still has the same probability of survival as a new window.

The experience with Klystron life, not including window failure, is given in Table IV-A-2, and as a histogram in Figure IV-A-2. The cumulative distribution is plotted on a Probability Chart, Figure IV-A-4. This distribution is approximately normal, with a mean life of 1400 hours and a standard deviation of 500 hours. In a sealed-off Klystron where failure may occur by either cathode or window failure independently, the probability of survival is the product of probabilities of survival under each of the two limiting factors. These probabilities are calculated in Table IV-A-3. The distribution is neither exponential or normal but approximately flat the first 1600 hours, Figure IV-A-4. The early losses are caused mainly by window failures, the later losses by cathode failures. The mean life is 1010 hours. The probable experience with a large number of tubes, such as the 480 or 920 proposed installation, can be closely estimated from the mean life.

At the present state of development with sealed-off Klystrons operating continuously at a peak power level of 17 megawatts, and 90% innage, tube failures would occur at the rate of almost exactly 10 per day, at the Stage I level, 480 Klystrons installed, or 19 per day at the Stage II level, 920 Klystrons installed.

The proposal states that initial operation will be at a power level of 6 megawatts and power will be increased as tube life permits, maintaining an acceptable level of tube replacement costs. It may be observed that the entire body of information which we have available on the life of Klystrons on the Mark III Accelerator can be given by three numbers which have been constants over a period of the last two years. These numbers are K = .005234 in the expression $P_w = e^{-kt}$ which describes the proportion of

windows surviving at any time t in hours, and the mean life, 1400 hours, and standard deviation, 500 hours, which describes the Gaussian distribution of cathode life. There is no data bearing on the variation of these numbers with the parameters of peak power level, repetition rate, pulse length, temperature or shelf storage time.

It appears to be a reasonable assumption that the lower power will increase life, perhaps radically, but we are completely unable to evaluate this assumption. We are also unable to evaluate the assumption that a Klystron having a mean life of 2000 hours, at a peak power of 22 megawatts, can be developed. There is no evidence that this assumption is untrue, but neither is it supported by any evidence acquired by operation of Mark I Klystrons up to this time.

A total of thirteen sealed-off Klystrons of the Mark I type have been produced to date. Of these thirteen, five failed with short lives for various reasons not connected with either output windows, or cathodes. Of the remaining eight, one is still in service, five failed due to output window punctures, and two due to cathode failure. All window failures occurred at lifetimes of around 100 hours. One cathode failure occurred at 348 hours, the other at 4000 hours. The sample is too small and process control too imperfect as yet to allow any conclusions to be drawn. The results are not, however, inconsistent with what might be expected from our computed probable life distribution.

Although objective evidence to support the assumed Klystron life is absent, we accept the assumptions of the proposal as the basis for establishing scale of Klystron production since they would seem to be a reasonable extrapolation of existing experience for both S and L bands. This production capability is as follows:

	Stage I
Total Klystrons required per month	175
New Tubes to be produced	10
Major Rebuilding	30
Minor Repairs	135

It would appear to be highly desirable to reduce the uncertainty connected with this phase of the proposal by increasing radically, and promptly, the scale of Klystron development work if the Two-Mile Proposal is accepted.

b. Klystron Development Cost

It is extremely difficult to estimate the probable cost of development since the course of such development is not at all clear at this time. Three such estimates are available for comparison. The Stanford Proposal estimates direct engineering effort at 73,008 hours, or approximately $310,000. If the supporting staff, purchases and overhead are allocated, pro rata, this becomes $1,630,00. One commercial producer has given a rough estimate of $600,000, and another "around $500,000". It is our feeling that these are low, for the reason that they do not appear to cover adequately the requirement for statistically significant proof of tube life in a sufficiently short time interval to keep tube development abreast of project requirements. They are also based on the assumption that tube development would be carried out for other purposes which reduced their estimates Also, operation of present accelerators or proposed prototype accelerators does not accumulate tube hours at a high enough rate to meet this requirement. Furthermore, the primary purpose of this operation has been, and probably will continue to be, to maintain accelerator operation rather than to test tubes. Such tube information as has been developed has been essentially a by-product of accelerator operation. It should be noted that Mark I Klystron performance has remained substantially the same over the past two years.

In order to free tube development from such dependence it should be established as a parallel and coordinated, but independent program. Life data should be accumulated on a continuously operated test stand, keeping ten tubes in the test stand. Such a stand will run up 7,000 tube hours per month. Since at least 20,000 tube hours will be required to give a reasonably reliable indication of performance at the desired level (10 tubes x 2000 hours) a three months period will be required to give such a demonstration. If the development goes through ten cycles of tube design, a total of 100 tubes would be constructed and tested to failure. The time for such testing would be approximately 24 months, assuming an original 1000 hours and final 2000 hours life. The minimum time required to organize, build and staff such a development facility would probably be on the order of 18 months.

The total cost might be expected to be of this magnitude:

5 Development Engineers	3-1/2 yrs. @ $8,000	$ 140,000
10 Technicians	3-1/2 yrs. @ $6,000	210,000
Overhead at 40%		140,000
Test Stand		500,000
100 Tubes @ $5,000		500,000
Program Power and Maintenance		60,000
Total Cost		$1,550,000

This is in good agreement with the Stanford figure of $1,630,000 when one considers it must include about $90,000 for the factory engineering and amounts for other tube development such as fundamental studies of windows and cathode material.

In view of the present uncertainty in both output energy level and cost of operation of the proposed Two-Mile Accelerator imposed by lack of definite information about Klystron performance, it appears that an expenditure of this order is well justified. It may also be cited that such a tube has other possible applications in radar use, and some support for its development is now derived from this interest. It is, of course, possible that commercial producers might undertake such a development program and absorb part or all of the cost, in view of the manufacturing potential. Such a possibility is worth investigation.

c. Klystron Factory Investment Cost Estimate

The scale of operations required to supply Klystrons at the production rates given in 3-a. has been checked by personal inspection of present processes, facilities and data at the Stanford Tube Shop, and independently by visits to two major manufacturers of high power Klystrons; Varian Associates and Litton Industries. Both of these organizations were informed as to the characteristics of the proposed Stanford Accelerator Klystron and had given consideration to the possibilities of its commercial production. Neither, however, was prepared to present a firm estimate of either facilities or production costs. As a result of these investigations, we believe that the scale of operations given in the Stanford Proposal is reasonable and in accordance with good commercial practice. While minor changes could be suggested, the

uncertainty imposed by the fact that the proposed tube has not yet been designed is so much greater that there appears to be no point in considering such possible minor changes. The detailed review of the Stanford estimate work sheets reveal no reason for making changes in their numbers. We further determined that no substantial changes in procedures have been made since the proposal was prepared so that the considerations on which the original work sheets were based are still valid.

Having verified the scope of physical plant, the cost elements entering into the estimate were reviewed. The factory may be divided into three separate functional divisions, represented by the first three items in Schedule B-1, Page 50 of the Stanford Proposal. These are:

Factory Services - parts fabrication, inspection, storage, equipment maintenance, plating and cleaning, offices.

Tube assembly.

Tube processing and testing.

Equipment for Factory Services and Tube Assembly is very largely an assemblage of standard commercially available units, such as machine tools, benches, furnaces, induction heating units, etc. These were readily estimated by reference to commercial price lists. Equipment for Tube Processing and Testing is specialized for the manufacture of a particular tube, and is in all cases, including that of the commercial plants visited, fabricated as an element of facilities construction cost. Cost records were available at Stanford to cover the fabrication of equipment currently used in processing Mark I Klystrons. These records provide the basis for checking costs of processing equipment. Our estimate of costs for this equipment follows:

Factory Services

Machine Shop (20 men)	$360,000
Inspection	15,000
Storage and Materials Handling	5,000
Equipment Maintenance	15,000
Plating and Cleaning	35,000
Offices	5,000
Misc. Special Shops, Glass, Ceramics, etc.	15,000
Total	$450,000

43633 O—59——32

Tube Assembly	$ 175,000
Tube Processing	610,000
Total Equipment	$1,235,000

The air conditioning cost is considered a part of building costs rather than equipment. The shop and storage space requirement, given in the Stanford Proposal, Table IV - C-1, as 30,000 square feet, is a reasonable allocation, falling in between estimates checked by observations of commercial practice in the two plants visited. Approximately 28,500 square feet of space requires good ventilation with washed air. The remaining 1500 square feet in the assembly area requires air conditioning with only moderately close control of temperature and humidity, but with very well filtered clean air supply.

The above factory will provide sufficient capacity to produce the original complement of 630 Klystrons on a one shift basis, with capacity for maintenance of Stage I operation on a one shift basis. Stage II Accelerator operation will require two shift operation of the Klystron factory. For the expanded output necessary for Stage II operation, an additional installation of tube processing equipment will be required. (See Stanford Schedule F, B, Page 58.)

Additional Processing Equipment $135,000

This estimate is in very close agreement with the Stanford Proposal estimate, which we feel was carefully and adequately prepared.

d. Klystron Production Cost

In the production of a Mark I Klystron amplifier tube, some 65 individual parts are assembled into a structure which weighs approximately 100 lbs. This structure may be regarded as being composed of essentially three groups of items; first, the main body, an all-metal sub-assembly comprising cavities, drift tube, and collector, second, the cathode sub-assembly comprising cathode, heater, shields, base insulator, and filament seals, and third, the external hardware such as cavity micrometers, cooling jackets and corona shields. The first group is assembled in a jig and parts joined by furnace brazing. The second group is assembled partially by

mechanical joints, partially by glass seal fusions and partially by brazing and welding. It is finally brazed to the main body assembly. The external hardware is mechanically attached to the main body and cathode assemblies. The process of parts production and assembly is well-defined and practice does not vary greatly between the three shops investigated.

Tube processing consists of evacuation, baking, formation of oxide cathode surface and finally, application of working voltages so that the tube is subjected to the maximum conditions of temperature, voltage, and current, during processing, that it will encounter in later operation. As the last step in processing, the proposed tube, having been tested to full operating loads while under continuous pumping, will be sealed off.

Somewhat greater variation in practice regarding tube processing was noted in comparing various shops. This, however, consisted largely in shifts of emphasis on the importance attached to the various operations so that the overall cost of processing probably does not show great variation.

It is not possible to make a detailed cost estimate of the sealed-off Klystron because it has not yet been designed. However, knowing its required characteristics, it is possible to estimate its cost by extrapolation of known costs of somewhat similar tubes, such as 2 and 5 megawatt commercial Klystrons, and the continuously pumped Mark I Klystron. Estimates made in this way, by several independent authorities, are in rather remarkably good agreement, under the circumstances, ranging from $3,000 to $5,000. Our considered opinion is that a cost of $4,000 per Klystron represents a good estimate of new tube cost.

As installed and operative, the Klystron includes, in addition to the tube itself, the focus coils and a lead shield to prevent excessive radiation of X-rays. The focus coils consist of three DC magnet coils, on separate spools, which are slipped over the tube body and secured in place. Weight of copper in the windings is approximately 35 lbs. per tube. Our estimate of the cost of these coils, in quantities of 500, is $200 for each set.

The lead shields weigh 187 lbs. each, and are simple cylindrical shapes. Our estimate of their cost is $80.00 each.

Estimated total cost for the initial installation, Stage I.

630 Klystrons @ $4,000	$2,520,000
500 Sets Focus Coils @ $200	100,000
500 Sets Lead Shields @ $80	40,000
	$2,660,000

e. Klystron Factory Operating Policies

As mentioned in Appendix IV-B, of the Stanford Proposal, several alternative methods of operation of the Klystron Factory can be considered. These include operation by Stanford as a part of the Accelerator Project or by a commerical organization. Both of these imply that the capital investment in such a plant would be a part of the project cost. Our discussions with commerical Klystron producers, however, disclosed the possible existence of a third alternative; purchase of Klystrons as a standard commercial product. One manufacturer has indicated an interest in producing such a Klystron in wholly owned facilities. We believe that this possibility is worth investigation since it would reduce project capital investment by over one million dollars, though possibly at the expense of some moderate increase in operating cost, at present unknown, since no firm estimate of commercial cost has been made. For comparison purposes, however, the Stanford estimate of new tube cost after applying an overhead allocation of 39.4% on staff salaries is $3,850 each. Commercial prices, in one case the result of rough calculation and in others a "guesstimate" extrapolated from experience in producing a somewhat similar tube, range from $3,500 each to "around $5,000" each for quantities over 1000. In view of the development status of the tubes, we regard these as representing remarkably close agreement.

It will be necessary to weigh the desirability of reliance on a commercially available Klystron for accelerator use against the undesirable inflexibility resulting from such a policy. While the scale of production for accelerator use alone is substantial, it is hardly large enough to allow division between two or more suppliers. In addition, the major part of the work in the operating phase will be in tube repairs. The program will thus be forced to rely on a single producer without close control of his activities. Such reliance for such an essential item, is obviously undesirable.

f. Annual Cost of Supplying Klystrons to the Accelerator

The estimated required numbers of tube replacements which we have used is that of the Stanford Proposal; 175 per month.

This is broken down into new tubes, major rebuilding and minor repair. We have used the previously quoted price for new tubes and the data in the Stanford work sheets for repairs. Stanford made a very detailed estimate which they compared to an estimate made by Varian. The Varian estimate was $1,450 for minor repairs and from $1,450 to $4,500 for major repairs. A check of the Stanford data indicated that they could probably do it for the stated amounts as they have no plant or development write-off in their figures, since these are provided separately.

The total of $2,820,000 differs from the Stanford total shown on their operating costs schedule for two reasons. It contains the 40% overhead proration and Stanford applied a 25% cost reduction factor. This appears optimistic to us.

Stage I	Per Month	Per Year	Est. Cost	Total
New Tubes	10	120	$4,000	$ 480,000
Major Rebuilding	30	360	2,000	720,000
Minor Repairs	135	1620	1,000	1,620,000
Total				$2,820,000
Stage II				$5,640,000

These costs are based on the assumption of the development of a tube having a mean life of 2000 hours, at the desired maximum power level, or the acceptance of a lower power level which will give this life. In the worst case which seems possible, a tube no better that the present Mark I Klystron operating at the 17 MW power level for which experience is available, the above costs would be almost exactly doubled, since under these conditions tube life would be approximately 1000 hours.

TABLE IV-A-1

FREQUENCY DISTRIBUTION, WINDOW LIFE
90 STANFORD MARK I KLYSTRON WINDOWS

1954 - 1957 incl.

	Failed			Surviving
Life-Hours	Number Incremental	Number Cumulative	Per cent Cumulative	Per cent Cumulative
0- 200	13	13	14	86
201- 400	7	20	22	78
401- 600	5	25	28	72
601- 800	5	30	33	67
801- 1000	6	36	40	60
1001- 1200	5	41	45	55
1201-*1400	3	44	49	51
1401- 1600	3	47	52	48
1601- 1800	5	52	58	42
1801- 2000	4	56	62	38
2001- 2200	3	59	66	34
2201- 2400	4	63	70	30
2401- 2600	3	66	73	27
2601- 2800	3	69	77	23
2801- 3000	1	70	78	22
3001- 3200	3	73	81	19
3201- 3400	3	76	84	16
3401- 3600	1	77	86	14
3601- 3800	1	78	87	13
3801- 4000	1	79	88	12
4001- 4200	0	79	88	12
4201- 4400	2	81	90	10
4401- 4600	2	83	92	8
4601- 4800	1	84	94	6
4801- 5000	0	84	94	6
5001- 6000	1	85	95	5
6001- 7000	2	87	97	3
7001- 8000	2	89	99	1
8001- 9000	0	89	99	1
9001-10000	1	90	100	0

* Half Life 1320 Hours.

TABLE IV-A-2

FREQUENCY DISTRIBUTION, TUBE LIFE
86 STANFORD MARK I KLYSTRONS, CONT. PUMPED
1956 & 1957

	Failed			Surviving
Life-Hours	Number Incremental	Number Cumulative	Per cent Cumulative	Per cent Cumulative
0- 200	1	1	1.1	99
201- 400	2	3	3.5	96
401- 600	5	8	9.2	91
601- 800	5	13	15	85
801-1000	7	20	23	77
1001-1200	10	30	35	65
1201-1400	15	45	52	48
1401-1600	10	55	64	36
1601-1800	11	66	77	23
1801-2000	6	72	84	16
2001-2200	9	81	94	6
2201-2400	2	83	97	3
2401-2600	1	84	98	2
2601-2800	1	85	99	1
2801-3000	1	86	100	0

Mean Life - 1400 Hours.

Std. Deviation - 500 Hours.

TABLE IV-A-3

CALCULATED PROBABILITY OF SURVIVAL, AND INCREMENTAL FAILURES, USING SMOOTHED DATA ON STANFORD EXPERIENCE, WINDOWS AND TUBES

Time-Hours	Probability of Window Survival P_w	Probability of Cathode Survival P_c	Probability of Tube Survival $P_w \times P_c$	Probable Failure ΔP
0- 200	.900	.995	.895	.105
201- 400	.811	.986	.800	.095
401- 600	.730	.964	.704	.096
601- 800	.658	.919	.605	.099
801-1000	.592	.841	.498	.107
1001-1200	.534	.727	.388	.110
1201-1400	.481	.579	.278	.110
1401-1600	.433	.421	.182	.096
1601-1800	.390	.273	.106	.076
1801-2000	.351	.159	.056	.050
2001-2200	.316	.081	.026	.030
2201-2400	.285	.036	.010	.016
2401-2600	.256	.014	.003	.007
2601-2800	.231	.005	.001	.002
2801-3000	.208	.001	.0002	.0008

P_w calculated from $P_w = e^{-.0005234\,t}$

P_c from table of probability, normal distribution, mean, 1400 hours; std. deviation, 500 hours.

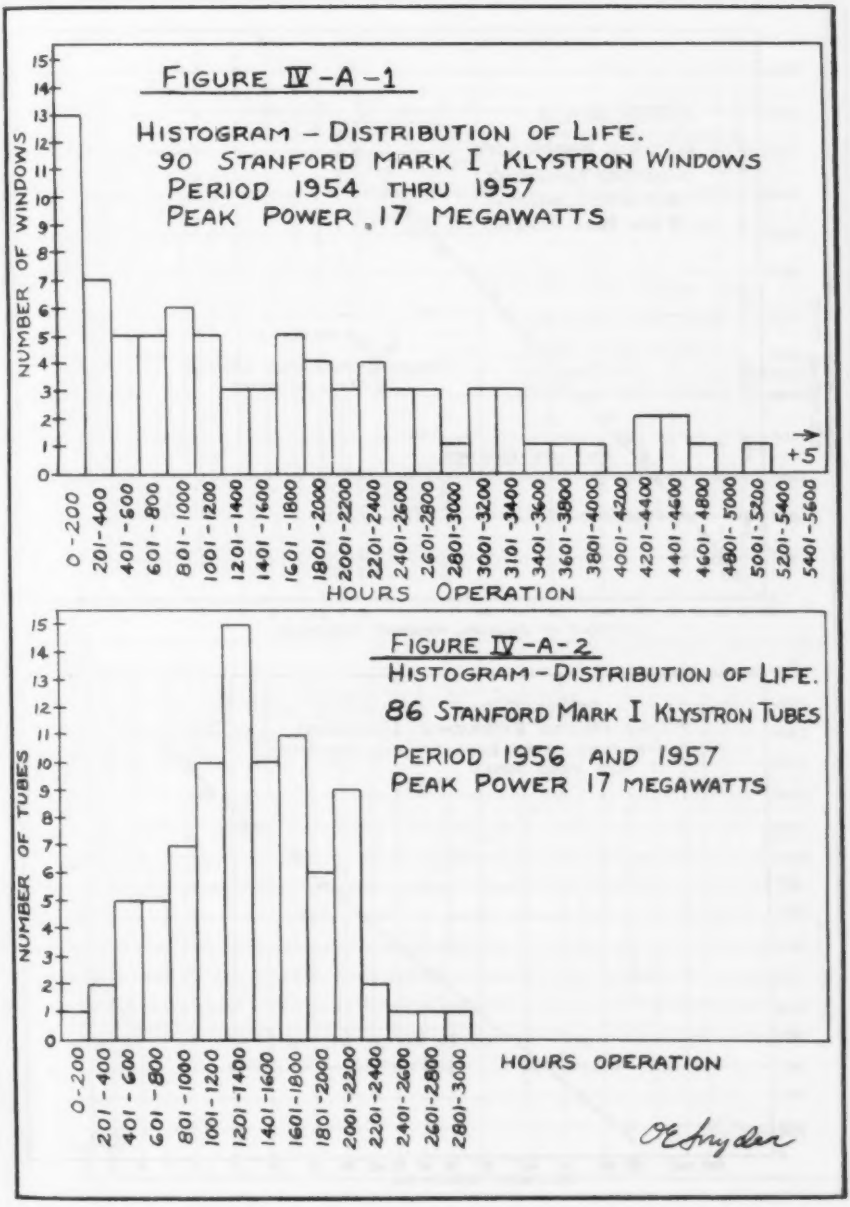


FIGURE IV-A-1
HISTOGRAM – DISTRIBUTION OF LIFE.
90 STANFORD MARK I KLYSTRON WINDOWS
PERIOD 1954 THRU 1957
PEAK POWER .17 MEGAWATTS
NUMBER OF WINDOWS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
+5
0-200
201-400
401-600
601-800
801-1000
1001-1200
1201-1400
1401-1600
1601-1800
1801-2000
2001-2200
2201-2400
2401-2600
2601-2800
2801-3000
3001-3200
3101-3400
3401-3600
3601-3800
3801-4000
4001-4200
4201-4400
4401-4600
4601-4800
4801-5000
5001-5200
5201-5400
5401-5600
HOURS OPERATION
FIGURE IV-A-2
HISTOGRAM – DISTRIBUTION OF LIFE.
86 STANFORD MARK I KLYSTRON TUBES
PERIOD 1956 AND 1957
PEAK POWER 17 MEGAWATTS
NUMBER OF TUBES
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0-200
201-400
401-600
601-800
801-1000
1001-1200
1201-1400
1401-1600
1601-1800
1801-2000
2001-2200
2201-2400
2401-2600
2601-2800
2801-3000
HOURS OPERATION
O. E. Snyder

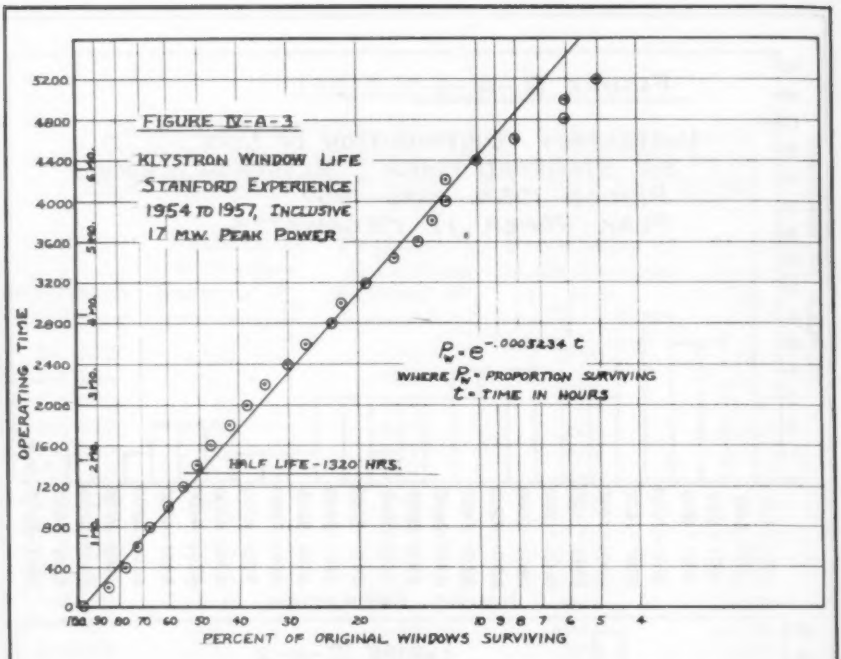


FIGURE IV-A-3
KLYSTRON WINDOW LIFE
STANFORD EXPERIENCE
1954 TO 1957, INCLUSIVE
17 M.W. PEAK POWER
$P_w = e^{-.0003234\,t}$
WHERE P_w = PROPORTION SURVIVING
t = TIME IN HOURS
HALF LIFE - 1320 HRS.
OPERATING TIME
PERCENT OF ORIGINAL WINDOWS SURVIVING

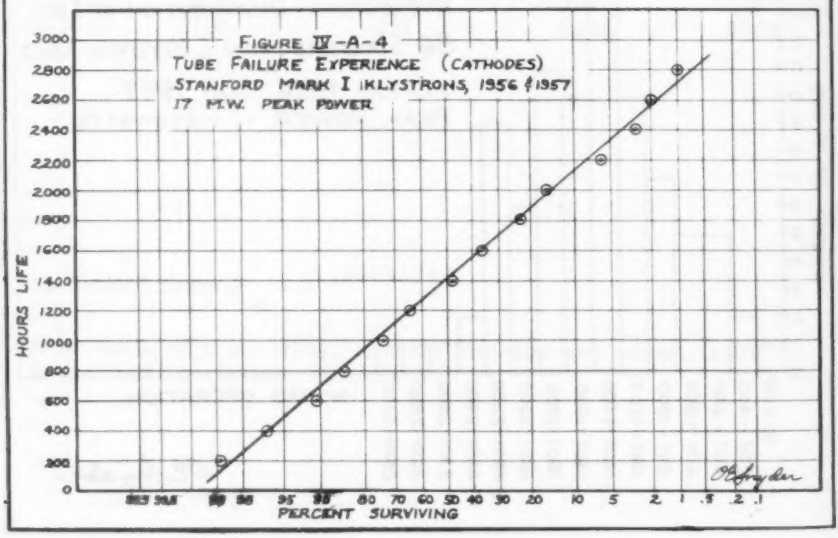
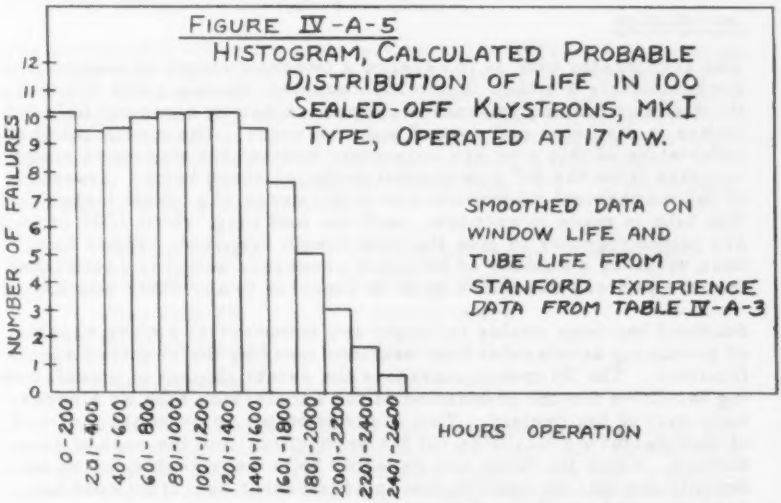
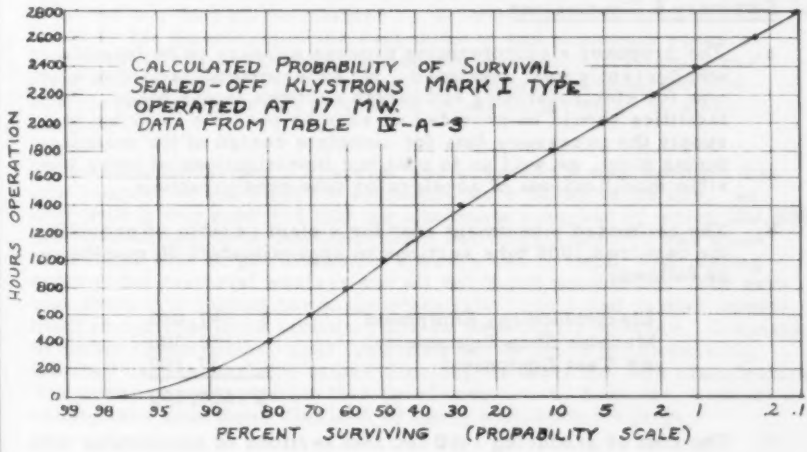


FIGURE IV-A-4
TUBE FAILURE EXPERIENCE (CATHODES)
STANFORD MARK I KLYSTRONS, 1956 & 1957
17 M.W. PEAK POWER
HOURS LIFE
PERCENT SURVIVING

FIGURE IV-A-5
HISTOGRAM, CALCULATED PROBABLE DISTRIBUTION OF LIFE IN 100 SEALED-OFF KLYSTRONS, MK I TYPE, OPERATED AT 17 MW.





O. E. Snyder

APPENDIX V

ACCELERATOR TUBE PRODUCTION

1. Introduction

The accelerator tube is in essence a two mile length of copper pipe, approximately 4 inches in outside diameter, having walls 3/8 inches thick and containing internal copper discs having a central hole 7/8 inches in diameter and spaced one inch apart. The electrical characteristics of this pipe are extremely critical for maximum energy transfer from the RF power input to the electron beam. Several of the mechanical tolerances are of the order of + .0002 inches. The tube is made in sections, each ten feet long, about 1000 of which are joined together to give the total length required. Tubes have been made by a number of different processes and it is established that the process described here is superior to any other now known.

Stanford has been unable to locate any commercial source capable of producing accelerator tube sections meeting the required specifications. The Proposal considers the establishment of manufacturing facilities for the production of the accelerator tube as a necessary part of the project. This study attempts to estimate the cost of manufacturing facilities for this production, and the cost of production. Since the tubes are expected to be serviceable for an indefinite period, no contribution to accelerator operation cost has been included for their replacement.

2. Summary & Conclusions

a. The proposed electroforming process appears to be feasible and currently well developed. No experimental facilities exist now for electroforming full length sections in one piece. Such facilities should be provided as soon as possible in order to supply the necessary data for complete design of the manufacturing plant, as well as to continue investigations of some possible modifications of accelerator tube configurations.

b. The estimated investment cost for a plant capable of providing the required 1000 tube sections in approximately 30 months is as follows:

Electroforming Equipment	$ 397,000
Machine Shop Equipment	250,000
RF Test Equipment	37,200
	$ 684,200

c. The cost of producing 1000 ten foot sections of accelerator tube is estimated to be as follows:

Materials	$ 401,750
Labor	1,910,830
	$2,312,580

3. Manufacturing Process

The accelerator tube consists of an electroformed section of disc loaded waveguide with input coupler and with flanges on the ends of the tube and the input branch. The supports, expansion joints and water jacket are estimated elsewhere.

The proposed process for manufacture of accelerator pipe sections has undergone considerable revision as a result of developments in the Stanford Laboratories since the preparation of their Proposal. The specifications for accelerator pipe sections remain however, as given in Section II., A. 3. of the Stanford Proposal and in greater detail in ML Report No. 258, Chodorow, et al., as published in "Review of Scientific Instruments," February 1955. These specifications in brief are as follows:

Section Length	10 feet, feed point to feed point
Guide ID	$3.2470 \pm .0002$
Disc Hole ID	$.8225 \pm .0002$
Disc Thickness	$.2300 \pm .0002$
Disc Spacing	$1.0335 \pm .001$

It is proposed to form this tube by electroforming copper over an assembly of copper discs and aluminum spacers to an outside wall thickness of 3/8 inches. The aluminum spacers are then etched away by sodium hydroxide solution, leaving cavities whose dimensional accuracy has been determined by the accuracy with which the aluminum spacers were machined. The close dimensional tolerances required are thus all maintained by the observation of such tolerances in the machining of the copper discs and aluminum spacers. The process has been demonstrated with entirely satisfactory results and the accelerator sections so produced are understood to be superior in electrical properties to any so far made by other methods.

At the time the Stanford Proposal was prepared it was intended that this process be used and the estimates were based on its use. At that time it was expected that the aluminum spacers, of which 120,000 are needed, would be machined from solid bar stock. It has since been found that forged aluminum spacers can be used, eliminating most of the material wastage and all but finish machining. The savings from this change are large since labor costs and capital investment in machine shop facilities are all drastically reduced. It seems probable that a further cost reduction can be made by purchasing punched copper washers rather than copper strip for disc manufacture. The possible savings from this development are, however, considerably less than those obtained by using aluminum forgings.

Further development of the electroforming process appears likely to reduce the plating time, currently four weeks per section, to perhaps as little as half this. No cost savings will result, however, since the increased size and unit cost of equipment approximately balances the decrease in number of units required. Labor cost will not be affected by such a change.

A major saving over the original estimate will also be effected by the design change in accelerator sections which has eliminated the separate RF coupler section. This is now made integrally with the accelerator tube, and almost the entire cost previously estimated disappears. These changes, which have all been satisfactorily proven to be feasible, are the chief reason for the large decrease in our estimate as compared to that of the Proposal.

4. Manufacturing Facilities

a. Electroforming Facilities:

Cleaning Equipment - 1 unit	$ 50,000
Plating Equipment - 15 units @ $20,000	300,000
Etching Equipment - 4 units @ $5,000	20,000
Materials Handling Equipment	5,000
Office and Misc.	2,000
Equipment Installation	20,000
	$ 397,000*

The space required is approximately 10,000 sq. ft. The floors should be acid resistant and very adequately drained. The space should be well ventilated. Air exhaust at tanks will require movement of 80,000 CFM. A large part of this may be introduced at tank top to reduce the cold weather room heating load.

The production capacity of this plant will be 30 ten foot tubes per month, or 1000 sections in slightly under three years.

b. Machine Shop Equipment:

Drill Presses 15"	2 @ $ 1,000	$ 2,000
Annealing Oven	2 @ $ 1,000	2,000
General Purpose 10" Tool Room Lathe	3 @ $ 3,000	9,000

* Compares to $364,450 in the Stanford estimate.

Comparator Guage	1 @ $ 4,000	$ 4,000
Broaching Tools & Press	5 @ $ 100	500
Turret Lathe 10"	3 @ $ 5,000	15,000
E E Monarch Lathe	8 @ $10,000	80,000
Index #55 Mill	2 @ $ 3,500	7,000
Shaper	1 @ $ 6,500	6,500
Lathe 16' Bed	2 @ $18,000	36,000
Do-all Saw	2 @ $ 4,000	8,000
Total Machine Tools		$ 170,000
Small Tool Accessories		30,000
Installation of Machine Tools		50,000
Total Machine Shop Equipment		$ 250,000*

The space requirement for the machine shop is approximately 10,000 sq. ft., 2500 sq. ft. of which is to be internally partitioned and air conditioned for close temperature control necessitated by high precision machine work. Conditions in this area are to be $68^{\circ} \pm 1^{\circ}$, and 40% RH + 5%. Internal heat load will be approximately 15 KW and 12 people continuously. The remainder of the shop requires normal comfort heating and ventilation.

c. RF Test Equipment:

Equipment for testing electrical properties of accelerator tube sections - 1 set @ $37,200

Space for this equipment has been provided as a part of the 2500 sq. ft. of air conditioned space listed under (b.) above.

d. Total Cost:

Electroforming Facilities	$ 397,000
Machine Shop Equipment	250,000
RF Test Equipment	37,200
Total Accelerator Fabrication Equip.	$684,200**

The difference in this figure as compared to that given in the Proposal, Schedule B-1. B. of 955,349, is due entirely to reduction in machine shop requirements because of developments in production techniques.

* Compares to $424,600 in the Stanford estimate.
** Compares to $955,349 in the Stanford estimate.

APPENDIX VI

EQUIPMENT ANALYSIS

1. Summary

a. The following major groupings of equipment are included in the construction budget.

Description	Section II Estimate x-1900	Section III Estimate x-1954
Klystron Factory	$ 1,370	$ 1,235
Accelerator Tube	684	684
Construction Tools and Test Instruments	680	---
All Other	1,912	2,592
Sub-total	$ 4,646	$ 4,511
Hauling & Handling	70*	1,146
Furniture & Office Equipment	470	470
Major Research Equipment	2,198**	4,098
Total	$ 7,384	$ 10,225

2. Discussion

The following schedules detail the estimates for this equipment.

a. Klystron Factory Equipment estimates are detailed in Appendix IV Section A-3.

Factory Service Equipment	$ 450,000
Tube Assembly Equipment	175,000
Tube Processing Equipment	610,000
Sub-total Stage I	$1,235,000
Stage II Additional	135,000
Total	$1,370,000

b. Accelerator Tube Fabrication & Testing Equipment estimates are detailed in Appendix V.

Electroforming Facilities	$ 397,000
Accelerator Machine Shop (Construction)	250,000
RF Test Equipment	37,200
	$ 684,200

* $1,076,000 in the Site, Utilities, Building and Tunnel estimates.
** $1,900,000 in the Site, Utilities, Building and Tunnel estimates.

c. All other fabrication and test equipment

This category was set up in the Stanford estimate as a "catch-all to" supply equipment not elsewhere included. No supporting detail was supplied and we were told that it resulted from taking a percentage of the construction budget based on experience.

In the following we have made an estimate of equipment requirements by type of employees, excluding the heavy handling equipment, in an attempt to arrive at a reasonable estimate for all equipment requirements and then subtracted the amounts otherwise included. The number of employees used is actually the estimated number for operation. The number for construction will be essentially the same in total except that there will be less scientists and more engineers. This does not affect this calculation appreciably. If additional equipment is needed during the construction phase, it can be obtained on a lease basis.

Class of Employee	Number		Equipment Per Man	Total
Scientists	90	x	10,000	$ 900,000
Engineers	36	x	10,000	360,000
Draftsmen & Designers	41	x	1,000	41,000
Accelerator Operators	50	x	1,000	50,000
Technicians	308	x	5,000	1,540,000
Machinists & Brazers	150	x	10,000	1,500,000
Crafts	73	x	5,000	365,000
Other	9	x	1,000	9,000
Maintenance	44	x	2,000	88,000
Administrative - clerks	198	x	1,000	198,000
Total				$5,051,000
Subtract:				
Klystron Factory	$1,235,000			
Accelerator Proper	684,000			
Office Equipment	470,000			
Hauling Equipment	70,000			2,459,000
All other Equipment Section III Schedule B-1				$2,592,000
Tools and Test Instruments Section II Schedule D				680,000
Total all other Equipment Section II Schedule D				$1,912,000

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d. Hauling and Handling Equipment

End Station, Etc.		
End Station Building Cranes	$857,200	
Magnet Handling Cars, Beam Switchyard	20,000	$877,200
Overhead Cranes Prototype & Accelerator Lab & Shop		21,000
Tunnel Jib Crane Electrical Cars		49,000
Tunnel Monorails		
Accelerator Tunnel	$ 81,000	
Cross Drift	21,000	102,000
Tunnel Elevators		27,000
Total Section II Schedule A		$1,076,200
Automobiles	$ 15,000	
Trucks, Fork Lifts, Etc.	55,000	70,000
Total Section III Schedule B-2		$1,146,200

e. Furniture, Storage and Office Equipment

Since this type of equipment is proportional to manpower, one can get a close approximation by using a rate per employee.

Group of Employees	Rate	Estimated Total
Scientists	90 @ $ 750	$ 68,000
Engineers	36 @ $ 750	27,000
Draftsmen	41 @ $ 300	12,000
Accelerator Operator Supv.	10 @ $ 500	5,000
Technician Supv.	60 @ $ 500	30,000
Machinists	150 @ $ 200	30,000
Crafts Supv.	7 @ $ 500	35,000
Other	9 @ $ 500	45,000
Maintenance	4 @ $ 500	20,000
Administrative & Clerical	198 @ $1000	198,000
Total (Section II Schedule D (Section II Schedule B-3	605	$470,000

This total was reconciled against an approximate listing of equipment and compared very favorably.

f. Major Research Equipment

This item was not in the Stanford construction estimate since it was their feeling that it was too early to predict what might be needed. They did show several "such as" items in their operating budget. They are of course entirely right that it is too early to estimate these items; however, since the AEC requires that the initial complement of research equipment be included in the construction budget, we are submitting the following on such a basis.

1) An initial set of counting equipment about equivalent to that on the Bevatron	$ 198,000
2) Research Magnets - Assumed Stanford Figures	1,000,000
3) Unspecified	1,000,000
Total Section II Schedule A	$2,198,000
4) 10,000 KW of motor-generator capacity to provide DC for magnets in the end station area. Includes AC feed, MG set, structure, cooling water and DC feed line.	1,900,000*
Total Section III Schedule B-4	$4,098,000

3. Conclusion

The equipment detailed above should be adequate for all phases of the construction project and provide for the initial complement of research and operating equipment.

*In Section II - A Site, Utilities, Building and Tunnel Estimate

APPENDIX VII

SECTION A

OPERATING COSTS

The following discusses the bases of calculation of the annually recurring costs after the project has passed the startup period. The same assumptions are used here as were stated in part IV of this report.

It also indicates the level of recurring plant and equipment costs and a total of the recurring costs.

As indicated in the following cost summary, this estimate exceeds the Stanford estimate by approximately $3,000,000. The differences are as follows:

1. Klystron Repair & Replacement + $520,000

   The degree of uncertainty of this portion of the estimate is large. This is discussed fully in Appendix IV. Stage I operation and a tube life of 2000 hours has been assumed. If Stage II operation and a tube life of 2000 hours were assumed approximately $3,000,000 additional would be required, however if a tube life of 4000 hours were assumed there would be only a small increase in the estimate. It appears that it will be necessary to adjust the parameters of tube life, number of tubes, tube repair costs and hours of operation to stay within practical budget limitations as the tube life increases with experience.

2. Accelerator Operation + $121,000

   This difference represents a netting of two factors; a larger estimate of the maintenance requirements by Brobeck, particularly with regard to the electronics and plant maintenance type personnel, and a larger estimate of miscellaneous supplies by Stanford. There is a large quantity of electronic, electrical and mechanical utilities that require constant maintenance, in addition to the accelerator proper. The enormity of the accelerator is hard to visualize. A good measure of maintenance requirements is capital investment. For comparison, this accelerator costs about four times the current value of the Bevatron. It appears that the Stanford scaling of about 125% of the Bevatron staff is too low. Although estimated on a different basis, we feel our estimate of about 200% of the Berkeley staff is more realistic. Supplies have likewise been estimated on the basis of Bevatron experience.

3. Research + $1,030,000

   This item is the major difference and is based on the above assumption of full utilization of the accelerator. This estimate includes

a greater number of scientific personnel and hence supporting personnel to obtain this utilization. Stanford assumes ten (10) senior staff members and forty (40) junior scientists at the graduate student level. This would appear to be too few considering the expense of building and operating this accelerator. It would appear to include essentially no provision for other than experimental physicists. Theoretical Physicists, Mathematicians, other scientists, computer personnel, etc., might also find the machine useful or serve as valuable backup personnel. In view of Stanford's desire not to employ this type of personnel, these people might take the form of visiting personnel from other universities or laboratories.

4. Administrative & General Service + $704,000

This increase is a result of the general scaling up of the administrative costs due to the larger number of direct personnel and a higher estimate of the plant maintenance requirements. The former is obvious. The latter is a matter of judgment. Because of the large investment in plant facilities, approximately $25,000,000, it is estimated that at least a maintenance amount of 2% should be used, even in the first few years. This would amount to over twice the Stanford estimate. We feel that even when the plant is new there may be large expenditures for such items as repairing tunnel cracks, repairing slide damage, repairing high voltage failures, DC generator repairs, replacement of pumps, etc. Also, there are the everpresent items that did not get into the initial construction or were installed wrong and hence, must be fixed.

5. Detailed Cost Comparison

	Number		*Dollars	
	Stanford	Brobeck	Stanford	Brobeck
Klystron Factory				
Engineers & Draftsmen	6	7	$ 40	$ 45
Technicians	75	128	495	862
Machinists & Brazers	25	43	165	291
Electro-Platers & Spec.	10	17	66	112
Sub-total			$ 766	$1,300
Material			965	1,000
Total	116	195	$ 1,731	$2,300
Accelerator Operations & Maintenance				
Accelerator Operators	46	46	$ 304	$ 300
Machinists & Brazers	50	30	330	183
Accelerator Technicians	63	45	416	275
Electronic Technicians	--	50	---	305
Maintenance & Crafts	--	25	---	153
Engineers & Draftsmen	--	20	---	132
Sub-total			$ 1,050	$1,348
Power			1,200	1,500
Other Materials			1,450	730
Total	159	216	$ 3,700	$3,578

*Shown in Thousands

	Number		* Dollars	
	Stanford	Brobeck	Stanford	Brobeck
Research				
Senior Scientist	10	10	$ 100	$ 130
Staff Scientist	-	**20	---	200
Junior Scientist	-	**20	---	140
Graduate Student	40	40	160	160
Engineers	8	25	69	200
Accelerator Operators	-	4	---	24
Draftsmen	31	19	205	95
Electronics Technician	75	50	495	325
Laboratory Technician	25	35	165	193
Mechanical Designer	-	6	---	36
Mechanical Technician***	-	-	---	---
Nurse	-	3	---	15
Photographer	-	2	---	10
Radiological Technician	-	4	---	24
Machinist & Brazer	62	60	409	366
Laborers	23	23	92	92
Other Crafts	-	25	---	165
Sub-Total			$ 1,695	$ 2,175
Power			210	210
Material			350	900
Total	274	346	$ 2,255	$ 3,285
Administrative & General Service				
Administrative, Assistants & Section Heads	38	38	$ 266	$ 266
Secretaries, Clerks, Help.	140	160	560	640
Maintenance	-	44	---	275
Sub-Total, Labor			$ 826	$ 1,181
Janitor & Plant Security - (Service Contracts)	(30)	(30)	****165	165
OASI Tax & Comp. Ins.			107	146
Group Life Ins. & Retire.			127	175
Plant Maintenance Contracts			****199	250
Communications			60	60
Travel			20	30
Misc. Utilities, Material & Other Costs			200	400
Total	178	242	$ 1,704	$ 2,407
University Allotment			$ ---	$ 250
Equipment not related to Construction			$ 650	$ 1,200
Total Operating Costs	727	999	$10,040	$13,020

* Shown in Thousands.
** Not necessarily Stanford Employees.
*** Included as Maintenance Men under "Administrative Service".
**** Stanford amounts were divided in this manner for comparison.

SECTION B

RECURRING PLANT & EQUIPMENT COSTS

	Stanford x 1000	Brobeck x 1000
1. General Plant		
a. Other 1,000 x 1/2	$ 500	$ *-1
b. DC Generators 200 x 1/4	50	*-2
c. Machine Improvements 2,000 x 1/4	500	500
d. Plant Improvements - General	---	500
	$ 1,050	$ 1,000
2. Line Items		
a. Large Magnetic Spectrometer	$ 600	$ 600
b. Bubble Chamber or Equivalent 2,000 x 1/2	1,000	1,000
c. Research Magnets - 1,000 x 1/2	500	*-3
d. Additional Observation House 1,500 x 1/4	375	375
e. Shielding Changes 3,000 x 1/4	750	750
	$ 3,225	$ 2,725
Total Recurring Costs	$ 14,313	$ 16,745

*-1 $1,000,000 put in Construction Budget for unspecified initial complement of large research equipment.

*-2 $1,900,000 in Construction Budget for 10,000 KW of DC power supply and structure.

*-3 Put in Construction Budget.

APPENDIX VIII

SPACE ANALYSIS

Shown below are two tables, a "Space Summary" provided by the construction program, and a "Personnel Summary" as indicated in the estimate of recurring costs.

It will be noted that the space provided is in reasonable agreement with the space requirements. This type of comparison is fairly valid for office type personnel and laboratory and shop personnel who remain at their benches all of the time. It, however, breaks down in the case of maintenance personnel and scientific personnel who spend a large fraction of their time in the structures which house the large accelerators or other equipment, or are outside. It also breaks down when shift work or part time employees are included.

The tables show space for 280 office type employees, of which it is estimated there will be 255. This is quite close, leaving room for Government contract administration personnel conference rooms, etc.

The tables show laboratory and office space for 105 employees with an estimated total of 105.

The tables show shop space for 470 persons with 471 estimated to be on the payroll. This includes a large number who work in the shop only a fraction of their time, hence the overall space per man figure appears low but should be satisfactory.

The remaining personnel are transients and work primarily in the storage areas, the accelerator area and outside.

The total space provided herein is 415,500 sq. ft. This differs only a small amount from the Stanford estimate of 393,500 sq. ft. The prime differences are increase in office space of 16,000 sq. ft., and switching of some of the accelerator shop space to storage space.

The increase in personnel shown in our estimate requires the additional office space and there was an apparent lack of storage space.

SPACE SUMMARY

Building	Type of Space (Sq. Ft.)					
	Office	*Small Labs.	Mech. Shop	Storage	Other	Total
End Station Main Building	--	--	--	--	200,000	200,000
End Station Lab. & Office	5,000	16,000	9,000	3,000	8,000	41,000
General Services	--	--	8,000	6,000	--	14,000
Klystron Factory	3,000	7,500	20,000	2,500	--	33,000
Accelerator Prototype	--	3,500	--	--	10,000	13,500
Accelerator Storage & Shops	--	--	23,000	23,000	--	46,000
Administration Building	16,000	--	--	--	--	16,000
Service & Engineering	16,000	--	--	--	--	16,000
Accelerator Control Room	--	3,000	--	--	2,000	5,000
D-C Generator Buildings	--	--	--	--	21,000	21,000
	40,000	30,000	60,000	34,500	241,000	405,500
Net Space for Personnel	28,000	21,000	47,000	2,000	(Indeterminate)	
Net Sq. Ft. per Person required	100	200	100	100	(Indeterminate)	
Number Accommodated	280	105	470	20	154	1029

* Includes office space for scientific personnel.

PERSONNEL SUMMARY

Type	Type of Space Required					
	Office	*Small Labs.	Shops	Storage	Other	Total
Scientific	-	50	-	-	-	50
Graduate Students	-	20	-	-	20	40
Engineers & Draftsmen	77	-	-	-	-	77
Admin. & Clerical	178	-	-	20	-	198
Electroplaters & Specialists	-	-	17	-	-	17
Machinists & Brazers	-	-	133	-	-	133
Electronic Technicians - Res.	-	-	30	-	20	50
" " - Accel.	-	-	20	-	30	50
Technician - Research	-	35	-	-	-	35
Technician - Klystron	-	-	128	-	-	128
Accelerator Techs. & Operators	-	-	11	-	-	11
Crafts & Maintenance	-	-	117	-	-	117
Janitors & Police	-	-	-	-	** 30	**30
Other	-	-	-	-	13	13
	255	105	456	20	113	949

* Includes office space for scientific personnel.

** Not Stanford Personnel.

APPENDIX IX

UNIVERSITY OVERHEAD ALLOWANCE

The following calculations have been made without the assistance of Stanford University. They point out that the amount included for University overhead is a matter to be settled by negotiation based on actual operating conditions at the time and, therefore, is not subject to advanced estimating. Before preparing our estimate, Stanford University personnel were contacted and they are still of the opinion that they are not in a position to provide estimates.

Since it is necessary for budget purposes and because the Commission has requested that an amount be included, the following estimates are presented.

1. First Two Years

During the early phases of the development and construction program the proposed project will depend very heavily on the University proper to provide facilities and services for this project. During this period it seems logical to assume that the rate will be comparable to that obtained from the "Mills Formula" reduced by the amount of indirect services provided with project funds. To obtain an approximate value of what this would amount to, one can use the estimated costs and staffing pattern for the first two years as presented in the Stanford report.

Average Direct Personnel	$\frac{83 + 330}{2} = 207$
Average Administrative Personnel	$\frac{18 + 89}{2} = 54$
Annual Rate Direct Personnsl	$3.25 \times 2080 = \$6,760$
Total Direct Salaries - Average First Two Years	$207 \times \$6,760 = \$1,399,320$
40% of Direct Labor	$.40 \times \$1,399,000 = \$560,000$
Administrative Effort charged to Contract	
Administrative $15 \times 3.45 \times 2080 = \$108,000$	
Clerical $39 \times 2.10 \times 2080 = \$171,000$	$\$279,000$
. Balance - $560,000 less $279,000	= $289,000

2. After Second Year

After the second year the method of operation changes quite radically. By this time the project will have acquired a nearly complete complement of administrative and service personnel and will be fairly

** Not Stanford Personnel.

independent of the University administration for day to day needs. The University, on the other hand, will supply many items in support of the project, a high percentage of which will be of intangible nature to which it is very difficult to apply a value. The most important of these is what might be termed the "good name of the University," i.e., the overall competence to ably administer such a project and to attract top quality personnel to assure maximum utilization of this expensive instrument. More tangible items would include:

a. University Management Costs.

b. Land Use Cost based on a realistic industrial use.

c. Indirect effects on the University operating costs.

d. Legal fees.

e. Liability Insurance and risk.

f. Use of University facilities by AEC supported personnel.

g. Support of the AEC project by other service and technical departments for which no direct charge is made.

During past years there has been considerable discussion concerning the above points in the case of other university contractors. Each case has its own unique characteristics. While it is impossible to apply any one of these to the Stanford situation, it is possible to infer from the pattern what an order of magnitude rate might be for the Stanford case. From a survey of rates paid other universities it would appear reasonable to arrive at a rate based on an average annual cost for the balance of the construction program and the first few years of operation. A rate of approximately 2% of the average annual costs over a range of from $10,000,000 to $15,000,000 or $250,000 per year would appear to be a reasonable amount to use for budget considerations. Since this amount approaches very closely the amount computed for the first and second years, the budget assumptions contained in this report include $250,000 for each year. The actual rate will probably be less than this amount and will, thus, be within the budget provided.

3. Land Use

Since a large fraction of the above is for land use, it may be well to briefly state what values might be expected to be if leased by the University to others.

The project requires a site of approximately 400 acres. Of this, approximately 100 acres are adjacent to Stanford Industrial Park and suitable for industrial development. A 99 year lease on this type of property after development is presently selling for about $30,000 per acre. Undeveloped, the land is probably worth not more than $20,000 or a total of $2,000,000.

The balance of the land is suitable for residential development and has a market value of approximately $10,000 to $12,000 per acre after development. Prior to development it would be more nearly $6,000.

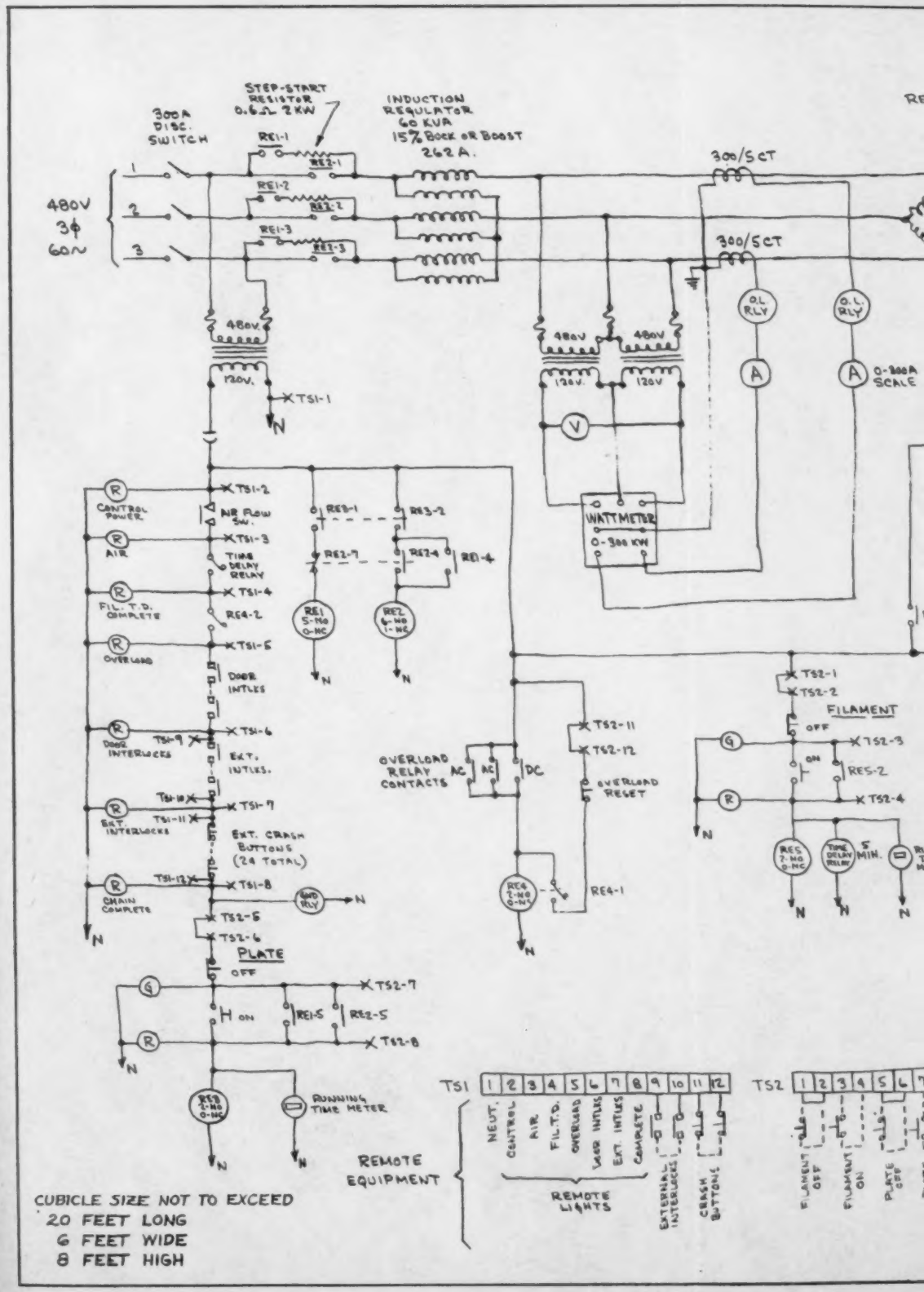
100 x 20,000	$ 2,000,000
300 x 6,000	1,800,000
Total	$ 3,800,000
Interest Return - 4%	$ 152,000

The above would apply on a long term basis. Since the land is not currently being used effectively nor will it all be put out of service during the first two years, any allowance should be covered by the "Mills Formula" during this period.

DRAWINGS - BROBECK

D-1 Klystron High Voltage Power Supply Schematic
D-2 Klystron Modulator Schematic
D-3 Deleted
D-4 Sector RF Driver & Trigger Schematic
D-5 Waveguide Arrangement - Stage I
D-6 Waveguide Arrangement - Stage II
D-7 Deleted
D-8 Klystron Cubicle Installation
D-9 Typical Modulator Control Requirements - Stage II
D-10 Vacuum System Schematic
D-11 Accelerator Tube Installation
D-12 Inflector & Deflector

II

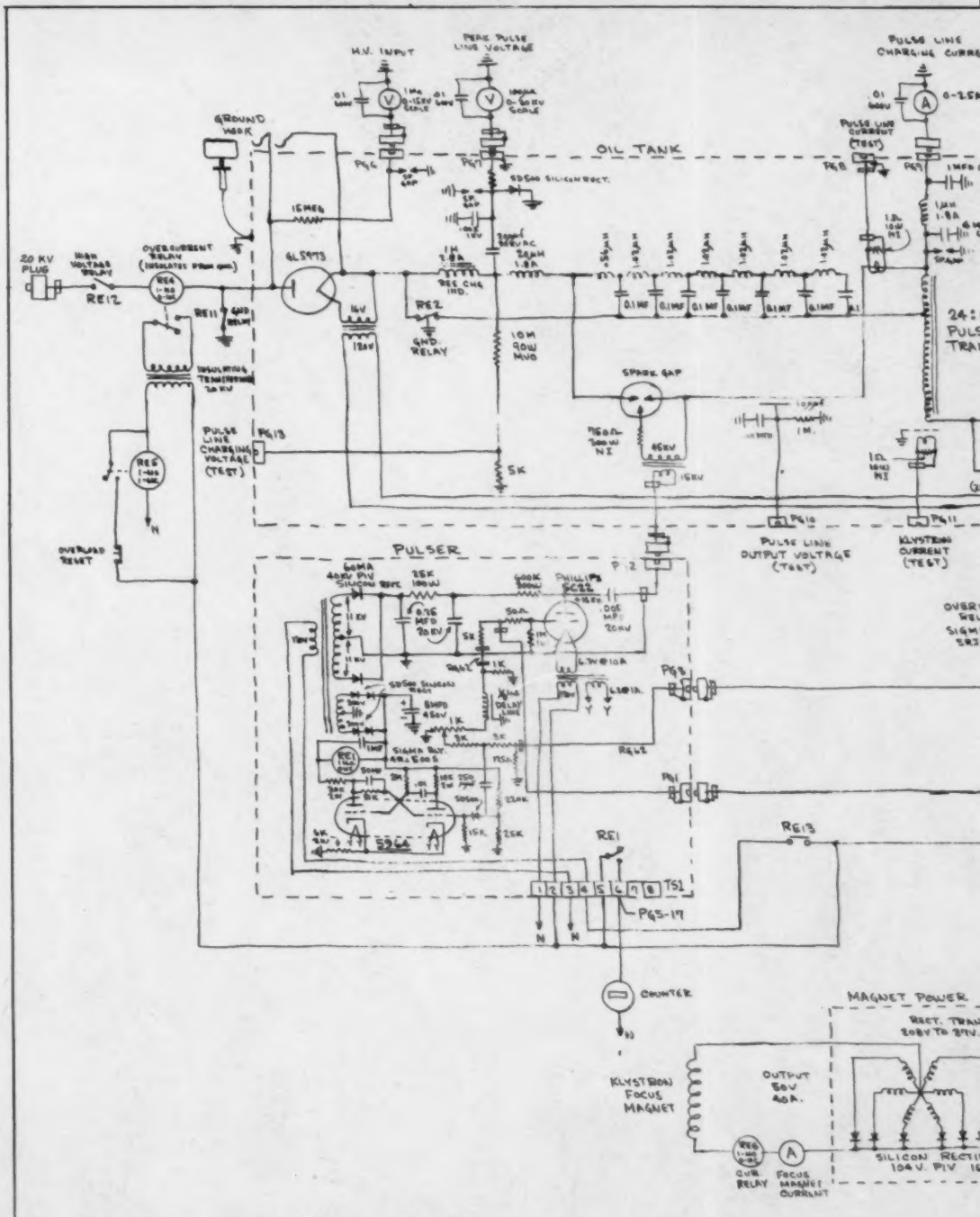

300A DISC. SWITCH
STEP-START RESISTOR 0.6Ω 2KW
INDUCTION REGULATOR 60 KVA 15% BOOK OR BOOST 262 A.
480V 3φ 60~
300/5 CT
300/5 CT
O.L. RLY
O.L. RLY
0-300A SCALE
480V
120V.
TS1-1
WATTMETER
0-300 KW
CONTROL POWER
AIR FLOW SW.
AIR
TIME DELAY RELAY
FIL. T.D. COMPLETE
OVERLOAD
DOOR INTLKS
DOOR INTERLOCKS
EXT. INTLKS.
EXT. INTERLOCKS
EXT. CRASH BUTTONS (24 TOTAL)
CHAIN COMPLETE
TS1-2
TS1-3
TS1-4
TS1-5
TS1-6
TS1-7
TS1-8
TS1-9
TS1-10
TS1-11
TS1-12
RE4-2
RE3-1
RE3-2
RE2-3
RE2-4
RE1-4
RE1 5-NO 0-NC
RE2 6-NO 1-NC
OVERLOAD RELAY CONTACTS
AC
AC
DC
OVERLOAD RESET
RE4-1
RE4 7-NO 0-NC
TS2-1
TS2-2
FILAMENT
OFF
ON
TS2-3
TS2-4
RE5-2
RE5 7-NO 0-NC
TIME DELAY RELAY
5 MIN.
PLATE
OFF
ON
TS2-5
TS2-6
TS2-7
TS2-8
RE1-5
RE2-5
RE6 7-NO 0-NC
RUNNING TIME METER
TS1
1 NEUT.
2 CONTROL
3 AIR
4 FIL. T.D.
5 OVERLOAD
6 DOOR INTLKS
7 EXT. INTLKS
8 CHAIN COMPLETE
9
10
11
12
REMOTE LIGHTS
EXTERNAL INTERLOCKS
CRASH BUTTONS
REMOTE EQUIPMENT
TS2
1
2
3
4
5
6
FILAMENT OFF
FILAMENT ON
PLATE OFF
CUBICLE SIZE NOT TO EXCEED
20 FEET LONG
6 FEET WIDE
8 FEET HIGH

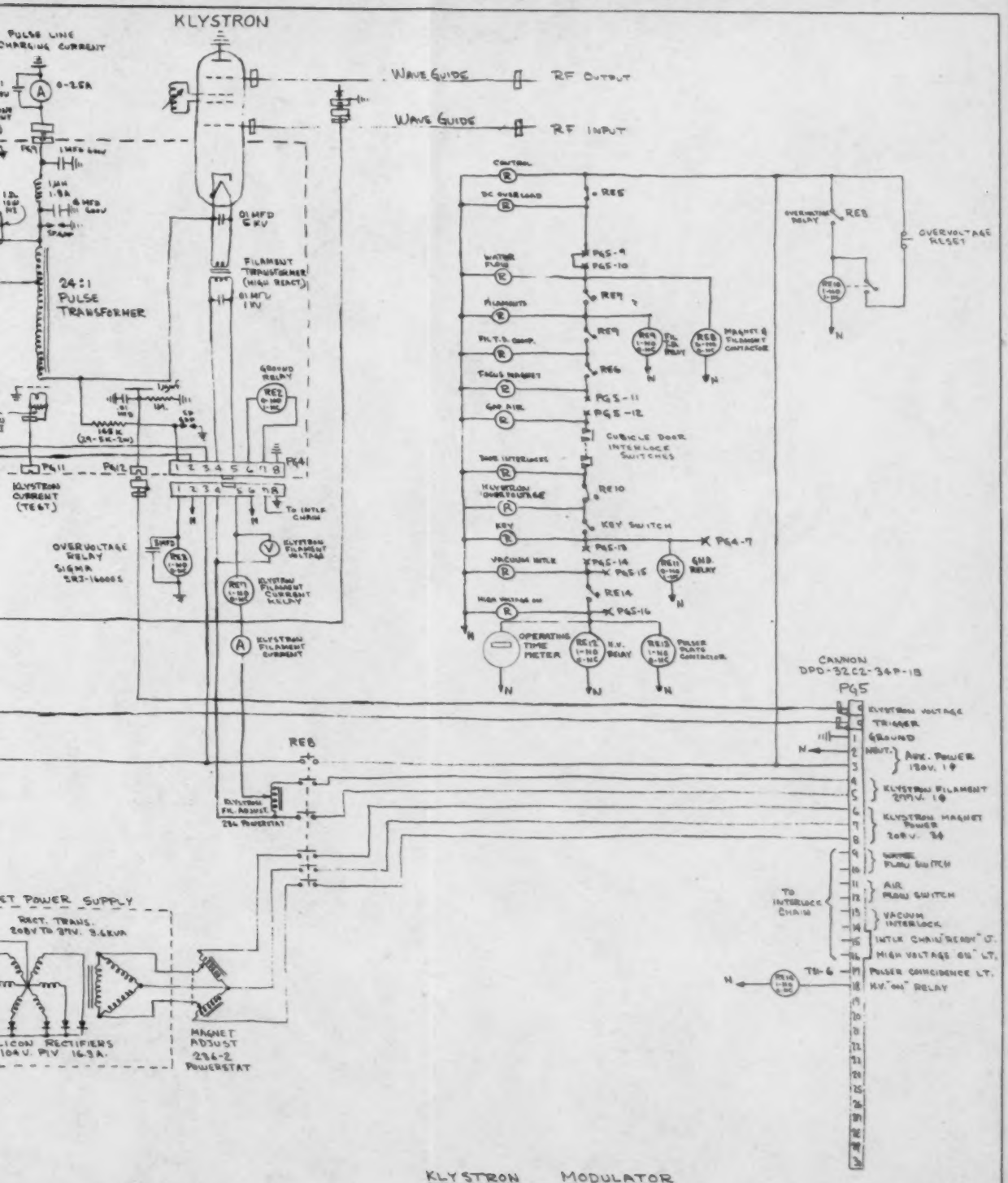
KLYSTRON HIGH VOLTAGE POWER SUPPLY SCHEMATIC

WILLIAM M. BROBECK & ASSOCIATES
1920 PARK BOULEVARD — OAKLAND 6, CALIFORNIA

By W.L. DEXTER Date 6/7/58 Ref 200-19-D1

For ATOMIC ENERGY COMMISSION

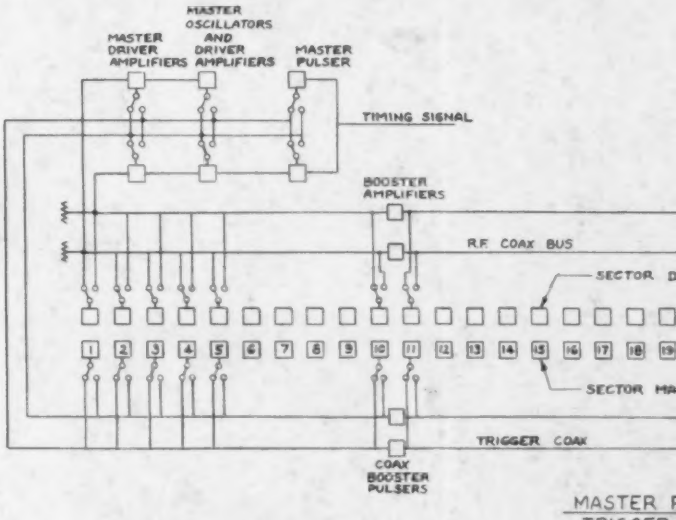

H.V. INPUT
PEAK PULSE LINE VOLTAGE
PULSE LINE CHARGING CURRE
GROUND HOOK
OIL TANK
20 KV PLUG
HIGH VOLTAGE RELAY
OVERCURRENT RELAY (INSULATED FROM GND)
RE12
RE11
GND RELAY
INSULATING TRANSFORMER 10 KV
6LS973
16V
12.6V
RE2
GND. RELAY
10M 90W MVO
SPARK GAP
45KV
15KV
5K
PULSE LINE CHARGING VOLTAGE (TEST)
PG13
OVERLOAD RESET
PULSER
P 12
PG3
PG2
PG1
RE1
RG13
TS1
PG5-17
PULSE LINE OUTPUT VOLTAGE (TEST)
KLYSTRON CURRENT (TEST)
PULSE LINE CURRENT (TEST)
COUNTER
MAGNET POWER
KLYSTRON FOCUS MAGNET
OUTPUT 50V 40A.
SILICON RECTI
104 V. PIV
GUN RELAY
FOCUS MAGNET CURRENT



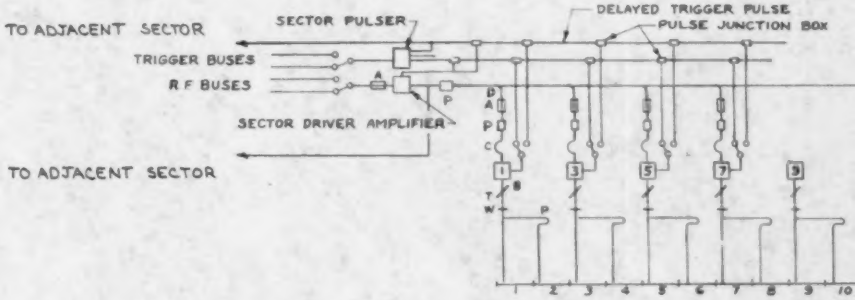
KLYSTRON MODULATOR

SCHEMATIC

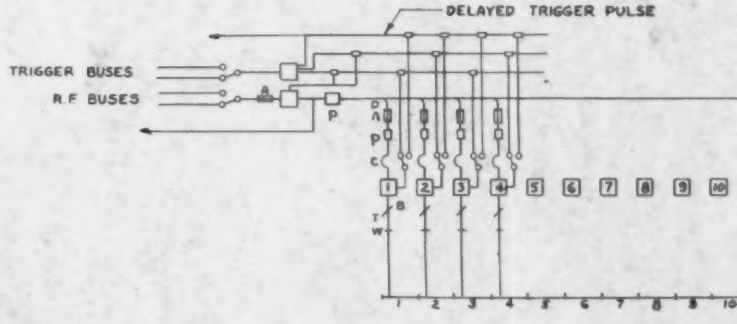
WILLIAM M. BROBECK & ASSOCIATES
1920 PARK BOULEVARD — OAKLAND 6, CALIFORNIA
By W.L. DEXTER Date 6/20/58 Ref 200-19-D2.
For ATOMIC ENERGY COMMISSION.



MASTER
TRIGGER
10,000



STAGE

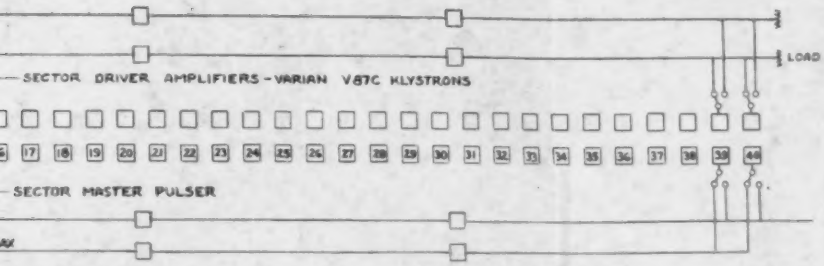


STAGE

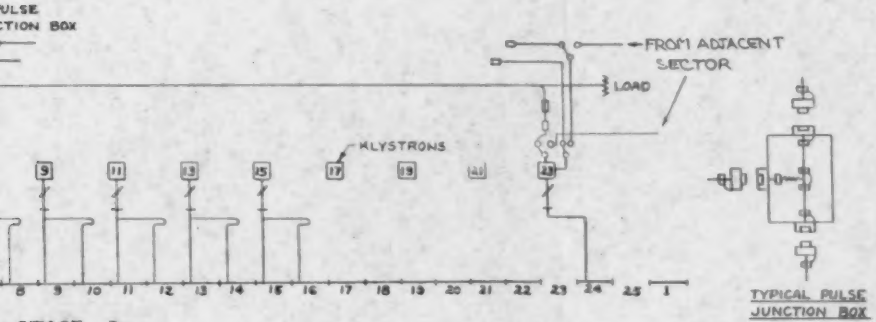
LEGEND

A ATTENUATOR
B BETHE HOLE COUPLER
C RG 8/U COUPLER
D 4-HOLE DIRECTIONAL COUPLER
T THERMISTOR BRIDGE
W WINDOW
P PHASE SHIFTER
P COAX RELAY

SECTOR R.F.
TRIGGER SC
250 FT

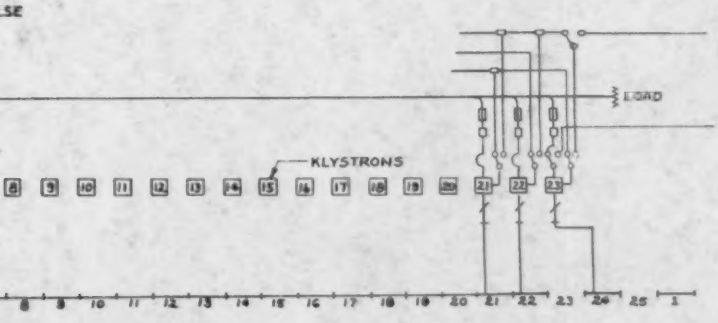


MASTER R.F. DRIVE AND
TRIGGER SCHEMATIC
10,000 FT.



TYPICAL PULSE JUNCTION BOX

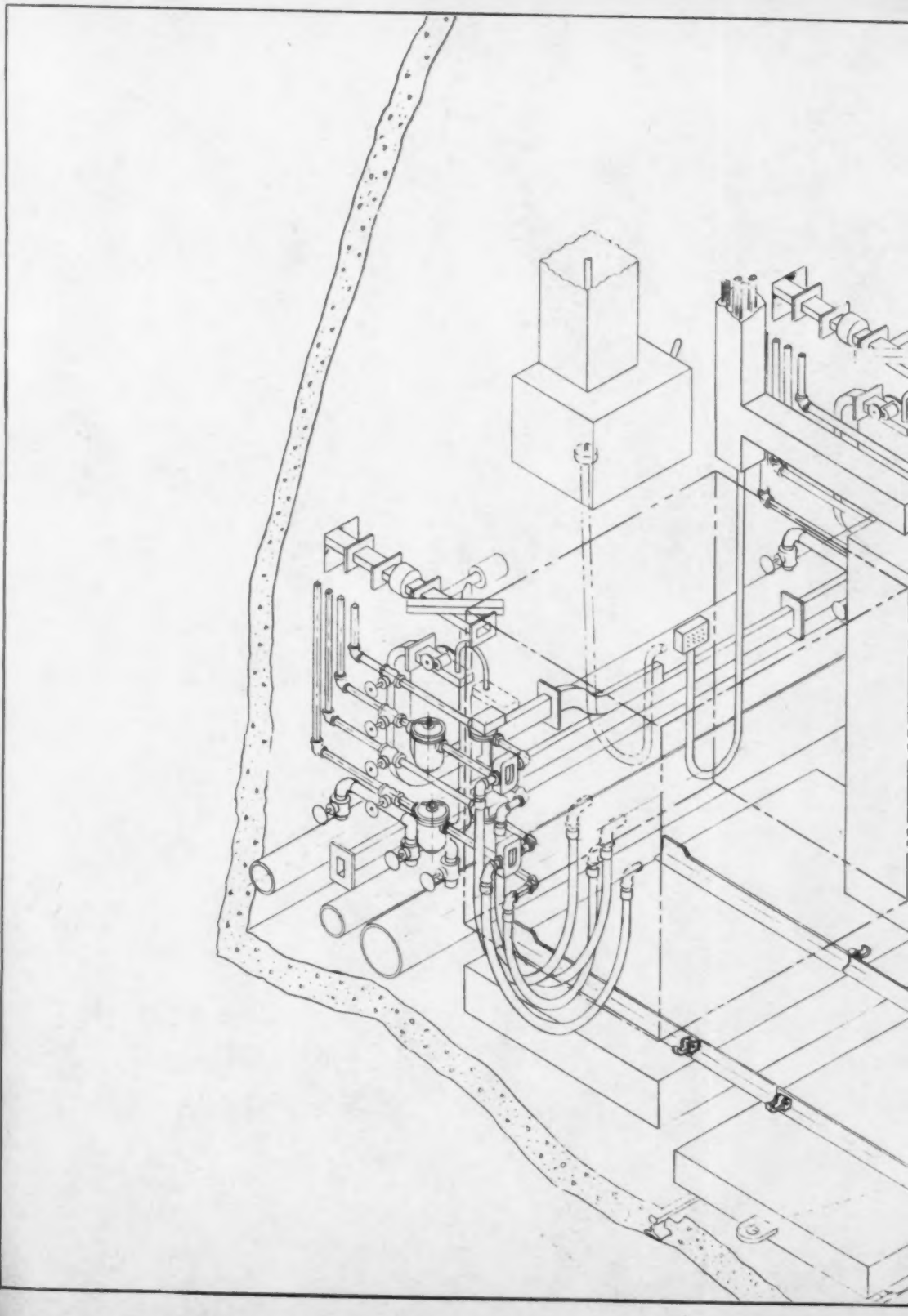
STAGE I



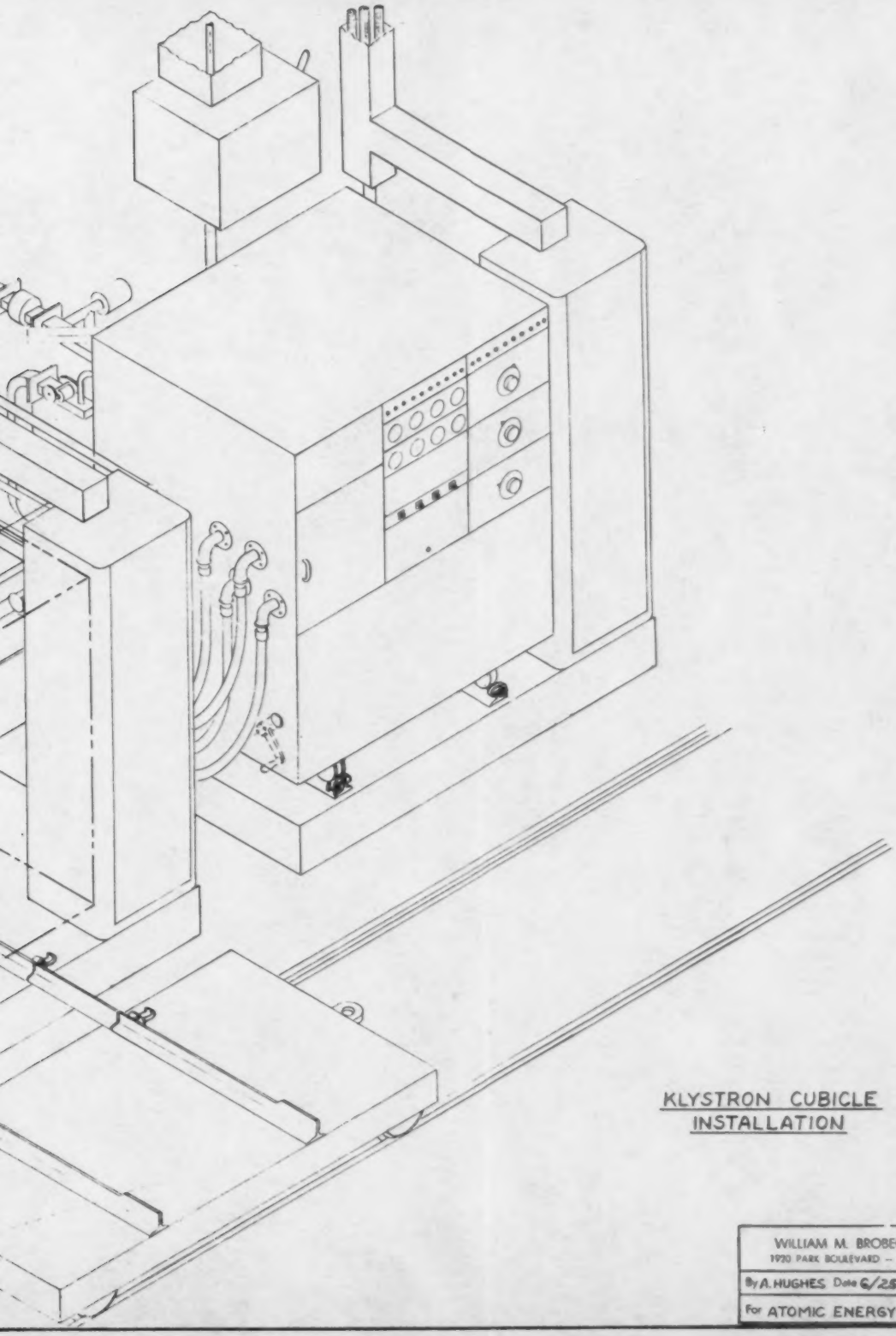
STAGE II

CTOR R.F. DRIVE AND
RIGGER SCHEMATIC
250 FT.

WILLIAM M. BROBECK & ASSOCIATES	
By R. SMITH	Date 6/27/58 Ref 200-19-D4
for ATOMIC ENERGY COMMISSION	



43633 O - 59 (Face p. 522) No. 4



KLYSTRON CUBICLE
INSTALLATION

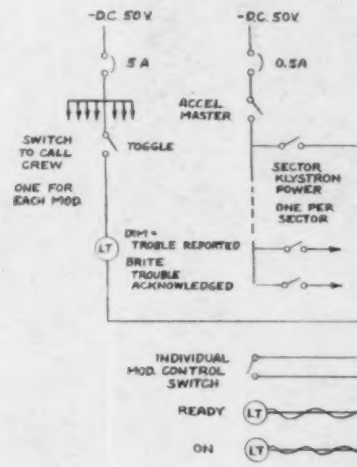
WILLIAM M. BROBECK & ASSOCIATES
1970 PARK BOULEVARD — OAKLAND 6, CALIFORNIA

By A. HUGHES Date 6/25/58 Ref 200-19-D8

For ATOMIC ENERGY COMMISSION

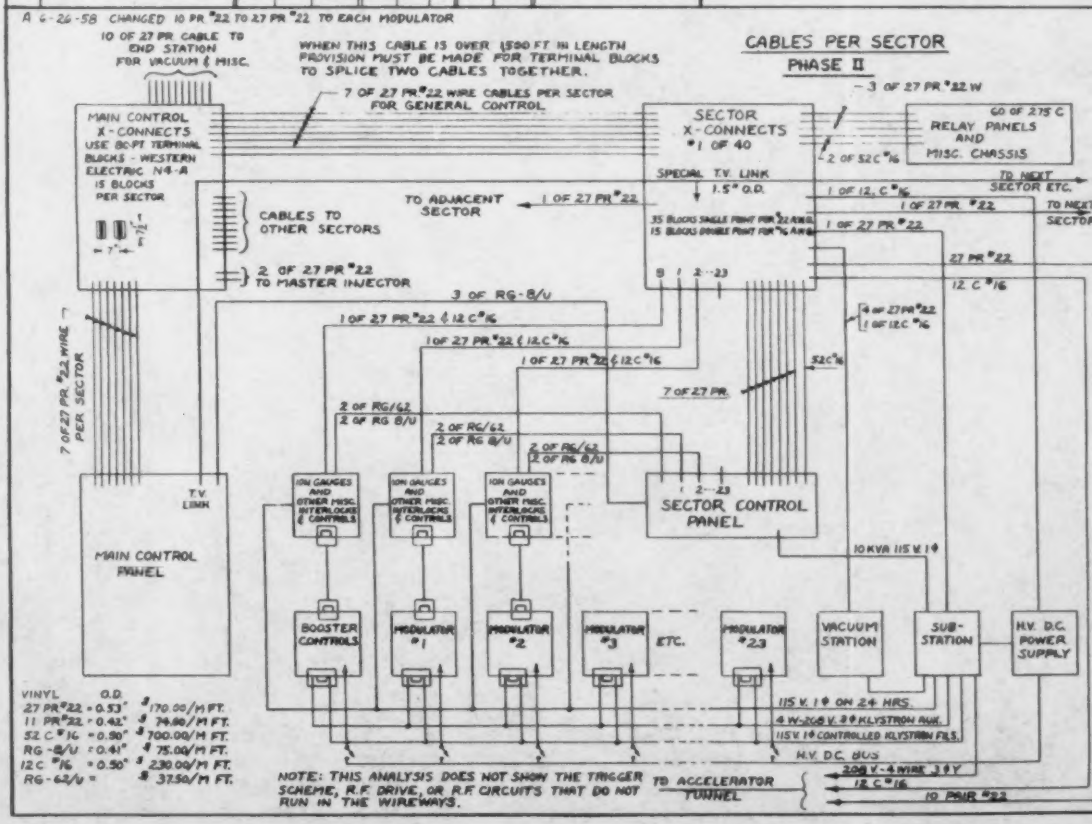
A. C-26-58 ADDITIONS
M.C.R. = MAIN CONTROL ROOM
S.C.R. = SECTOR CONTROL ROOM

ITEM	CONTROL FUNCTION	NUMBER OF CONTROLS AT EACH LOCATION M.C.R.	S.C.R.	MODUL.	INDICATORS PER SECTOR LIGHT	METER	SCOPE	WIRES EACH TO M.C.R.	FROM S.C.R. TO EACH	NOTES
1	SECTOR AND MODUL AUXILIARY	41	1	PERMISSIVE				2	-	
2	KLYSTRON FILIMENTS	82	2	PERMISSIVE				4		STANDBY OR FULL VOLTAGE
3	H.V. D.C. ON/OFF	41	1		1			2		
4	" " LEVEL CONTROL UP / DOWN / BROWN	80	2		1	2		10		
5	SECTOR PHASE CONTROL UP / DOWN / BROWN	86	2		2	1		6		5 WIRES TO BOOSTER & 1 WIRE TO MOD
6	MODULATOR CONTROL	961	24		46			146	4	SEE DIAGRAMS AT RIGHT
7	STEERING MAGNETS	160	2			2		8		
8	ACCELERATOR VAC SYSTEM	1000	25		50	5		104	2	81 WIRES TO VACUUM STATION
9	RADIATION GATE	10 KEYS	1 KEY					12		
10	COMMUNICATIONS							12	8	
11	MASTER R.F PULSE	1	24						4	LINE SELECTOR & TO INJECTOR
12	MASTER TRIGGER	1	24						4	LINE SELECTOR & TO INJECTOR
13	SECTOR DRIVE ATTENUATOR	44				44		12	8	
14	T.V. MONITOR CONTROL	-								SPECIAL CABLE
15	INJECTOR, MAIN	4						-	-	8 TO INJECTOR
16	REPAIR CREW CALL	1000			25			50	2	
17	END STATION VACUUM	16			32	22				M.C.R. ONLY NOT IN S.C.R.
18	FOCUSSING COILS	80	2			1		9		
19										
20										
21	BOOSTER POWER					1				ON WITH SECTOR AUXILIARIES
22	MODUL. H.V. CHARGING - VOLTS					23			2	
23	" " CURRENTS					23			2	
24	KLYSTRON H.V.						1		1 COAX	
25	ACCELERATOR R.F.								1 COAX	SPECIAL SCANNER
26	AVERAGE R.F. POWER						1	1 ϕ/u	1 ϕ/u	
27	PULSED INFLECTOR H.V.		3			2	1			1 COAX
28	" " CURRENT		1							1 COAX FROM CUP
29	C.W. DEFLECTOR MAGNET		2			1	1			1 COAX
30										
31	INJECTOR TEST ELECTRON GUN		3		1	1	1			
32										
33	MODULATOR ATTENUATOR		24			24			8	
34	MODULATOR PHASE CONTROL		24						6	
35	ACCELERATOR DIFF PHASE METERS					24			2	
						175		373	55	

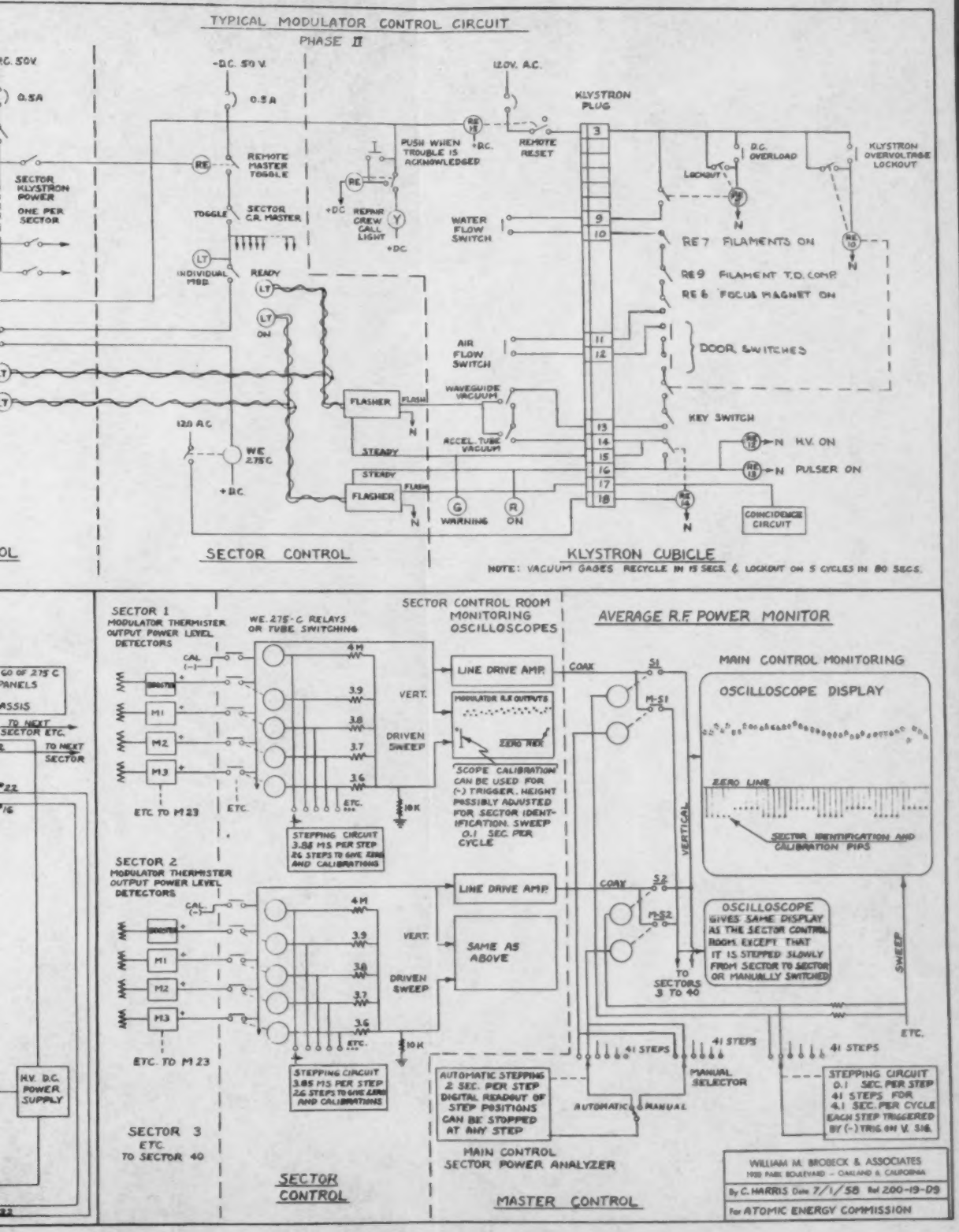


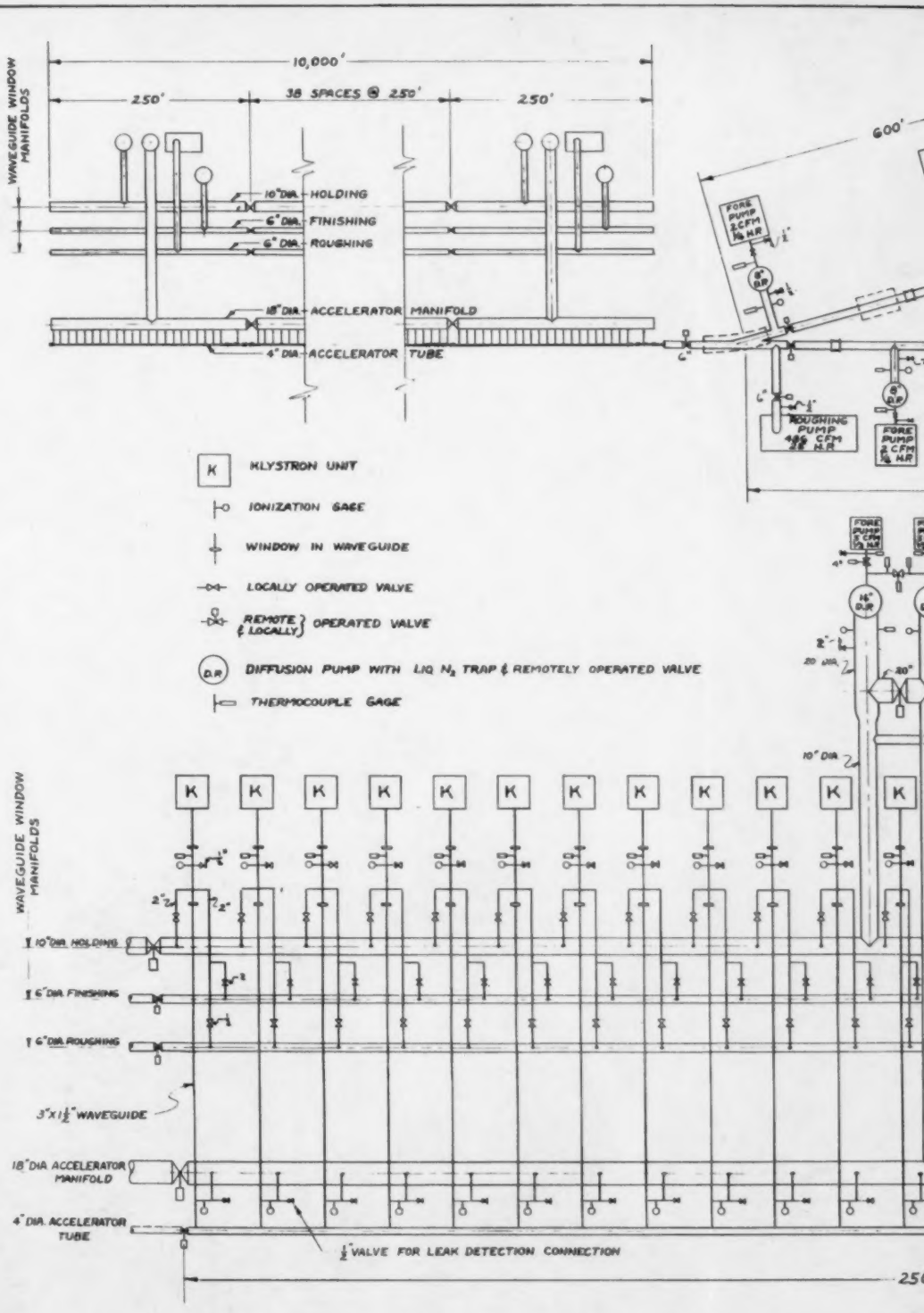
MASTER CONTROL

A. C-26-58 CHANGED 10 PR #22 TO 27 PR #22 TO EACH MODULATOR


10 OF 27 PR CABLE TO END STATION FOR VACUUM & MISC.
WHEN THIS CABLE IS OVER 1500 FT IN LENGTH PROVISION MUST BE MADE FOR TERMINAL BLOCKS TO SPLICE TWO CABLES TOGETHER.
7 OF 27 PR #22 WIRE CABLES PER SECTOR FOR GENERAL CONTROL
MAIN CONTROL X-CONNECTS USE 80 PT TERMINAL BLOCKS - WESTERN ELECTRIC N4-A 15 BLOCKS PER SECTOR
CABLES TO OTHER SECTORS
TO ADJACENT SECTOR
1 OF 27 PR #22
2 OF 27 PR #22 TO MASTER INJECTOR
3 OF RG-8/U
1 OF 27 PR #22 & 12 C #16
7 OF 27 PR #22 WIRE PER SECTOR
T.V. LINK
MAIN CONTROL PANEL
ION GAUGES AND OTHER MISC. INTERLOCKS & CONTROLS
2 OF RG/62
2 OF RG 8/U
SECTOR CONTROL PANEL
10 KVA 115 V 1 ϕ
BOOSTER CONTROLS
MODULATOR #1
MODULATOR #2
MODULATOR #3
ETC.
MODULATOR #23
VACUUM STATION
SUB-STATION
H.V. D.C. POWER SUPPLY
115 V. 1 ϕ ON 24 HRS.
4 W-208 V. 3 ϕ KLYSTRON AUX.
115 V. 1 ϕ CONTROLLED KLYSTRON FILS.
H.V. D.C. BUS
208 V - 4 WIRE 3 ϕ Y
12 C #16
10 PAIR #22
TO ACCELERATOR TUNNEL
CABLES PER SECTOR
PHASE II
3 OF 27 PR #22 W
60 OF 27 C RELAY PANELS AND MISC. CHASSIS
2 OF 52 C #16
SPECIAL T.V. LINK 1.5" O.D.
TO NEXT SECTOR ETC.
1 OF 12, C #16
1 OF 27 PR #22
35 BLOCKS SINGLE POINT PER 24 AWG
15 BLOCKS DOUBLE POINT FOR #16 AWG
27 PR #22
12 C #16
4 OF 27 PR #22
1 OF 12 C #16
52 C #16
7 OF 27 PR.
VINYL O.D.
27 PR #22 = 0.53" $ 170.00/M FT.
11 PR #22 = 0.42" $ 74.80/M FT.
52 C #16 = 0.90" $ 700.00/M FT.
RG-8/U = 0.41" $ 75.00/M FT.
12 C #16 = 0.50" $ 230.00/M FT.
RG-62/U = $ 37.50/M FT.
NOTE: THIS ANALYSIS DOES NOT SHOW THE TRIGGER SCHEME, R.F. DRIVE, OR R.F. CIRCUITS THAT DO NOT RUN IN THE WIREWAYS.

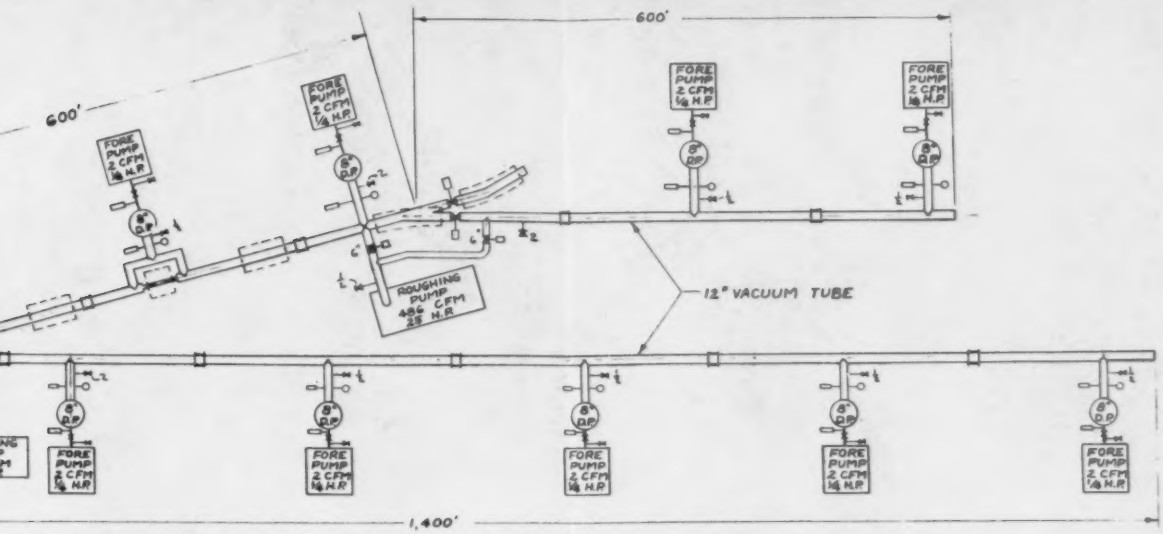
43633 O - 59 (Face p. 522) No. 5


TYPICAL MODULATOR CONTROL CIRCUIT
PHASE II
-D.C. 50 V.
0.5A
120V. A.C.
KLYSTRON PLUG
SECTOR KLYSTRON POWER ONE PER SECTOR
REMOTE MASTER TOGGLE
SECTOR C.R. MASTER
TOGGLE
PUSH WHEN TROUBLE IS ACKNOWLEDGED
REMOTE RESET
REPAIR CREW CALL LIGHT
D.C. OVERLOAD
LOCKOUT
KLYSTRON OVERVOLTAGE LOCKOUT
WATER FLOW SWITCH
RE 7 FILAMENTS ON
RE 9 FILAMENT T.D. COMP.
RE 6 FOCUS MAGNET ON
INDIVIDUAL MOD.
READY
ON
AIR FLOW SWITCH
DOOR SWITCHES
WAVEGUIDE VACUUM
FLASHER
FLASH
STEADY
ACCEL. TUBE VACUUM
KEY SWITCH
H.V. ON
PULSER ON
120 A.C.
W.E. 275 C
+D.C.
WARNING
ON
COINCIDENCE CIRCUIT
SECTOR CONTROL
KLYSTRON CUBICLE
NOTE: VACUUM GAGES RECYCLE IN 15 SECS. & LOCKOUT ON 5 CYCLES IN 80 SECS.
SECTOR 1
MODULATOR THERMISTER OUTPUT POWER LEVEL DETECTORS
W.E. 275-C RELAYS OR TUBE SWITCHING
SECTOR CONTROL ROOM MONITORING OSCILLOSCOPES
AVERAGE R.F. POWER MONITOR
MAIN CONTROL MONITORING OSCILLOSCOPE DISPLAY
LINE DRIVE AMP.
MODULATOR R.F. OUTPUTS
ZERO REF.
SCOPE CALIBRATION CAN BE USED FOR (-) TRIGGER. HEIGHT POSSIBLY ADJUSTED FOR SECTOR IDENTIFICATION. SWEEP 0.1 SEC. PER CYCLE
VERT.
DRIVEN SWEEP
COAX
ZERO LINE
SECTOR IDENTIFICATION AND CALIBRATION PIPS
VERTICAL
SWEEP
ETC. TO M 23
STEPPING CIRCUIT 3.85 M.S. PER STEP 26 STEPS TO GIVE ZERO AND CALIBRATIONS
SECTOR 2
MODULATOR THERMISTER OUTPUT POWER LEVEL DETECTORS
SAME AS ABOVE
OSCILLOSCOPE GIVES SAME DISPLAY AS THE SECTOR CONTROL ROOM EXCEPT THAT IT IS STEPPED SLOWLY FROM SECTOR TO SECTOR OR MANUALLY SWITCHED
TO SECTORS 3 TO 40
41 STEPS
AUTOMATIC STEPPING 2 SEC. PER STEP DIGITAL READOUT OF STEP POSITIONS CAN BE STOPPED AT ANY STEP
MANUAL SELECTOR
AUTOMATIC & MANUAL
STEPPING CIRCUIT 0.1 SEC. PER STEP 41 STEPS FOR 4.1 SEC. PER CYCLE EACH STEP TRIGGERED BY (-) TRIG. ON V. 516
SECTOR 3 ETC. TO SECTOR 40
MAIN CONTROL SECTOR POWER ANALYZER
SECTOR CONTROL
MASTER CONTROL
TO NEXT SECTOR ETC.
TO NEXT SECTOR
H.V. D.C. POWER SUPPLY
WILLIAM M. BROBECK & ASSOCIATES
2400 PARK BOULEVARD — OAKLAND 6, CALIFORNIA
By C. HARRIS Date 7/1/58 Ref 200-19-D9
For ATOMIC ENERGY COMMISSION

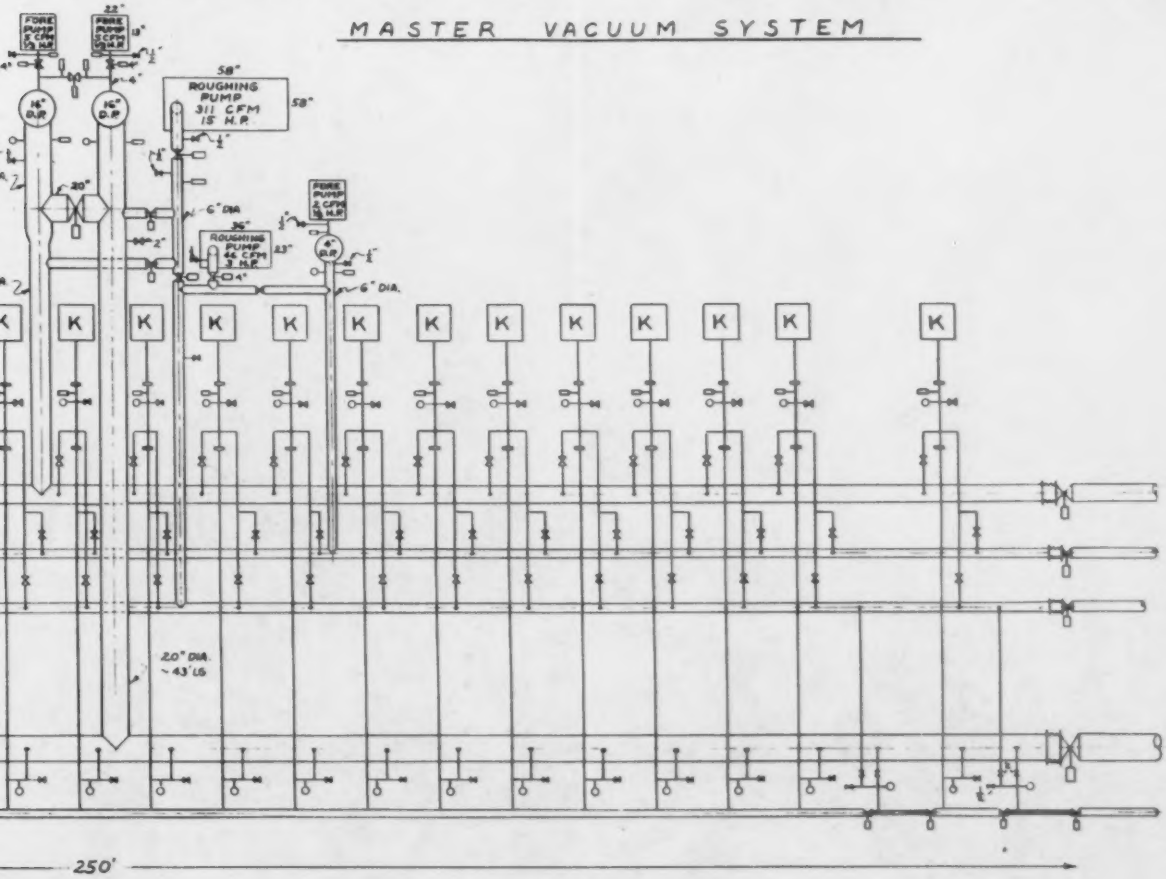


SECTOR VACUUM S

43633 O – 59 (Face p. 522) No. 6

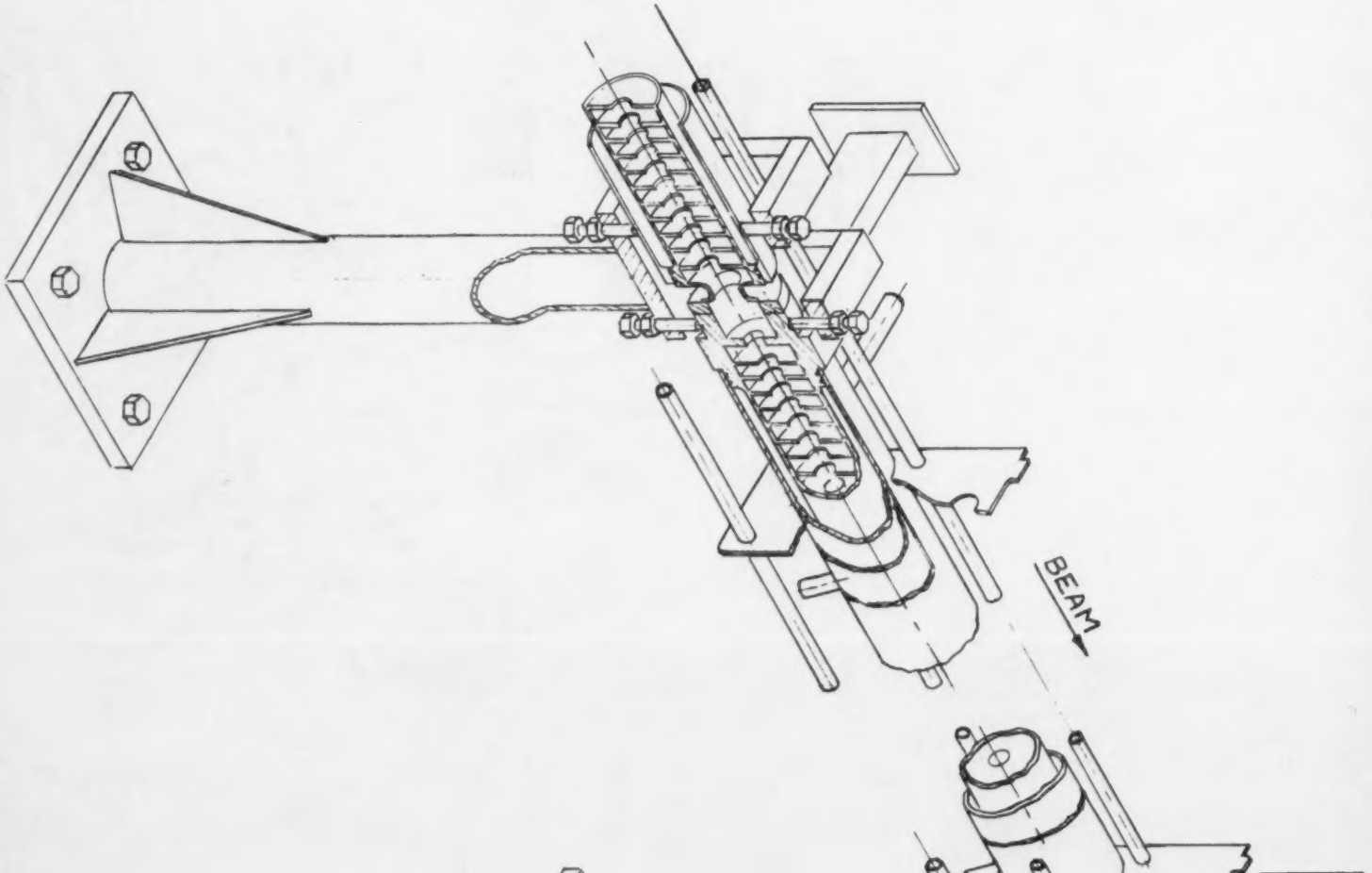


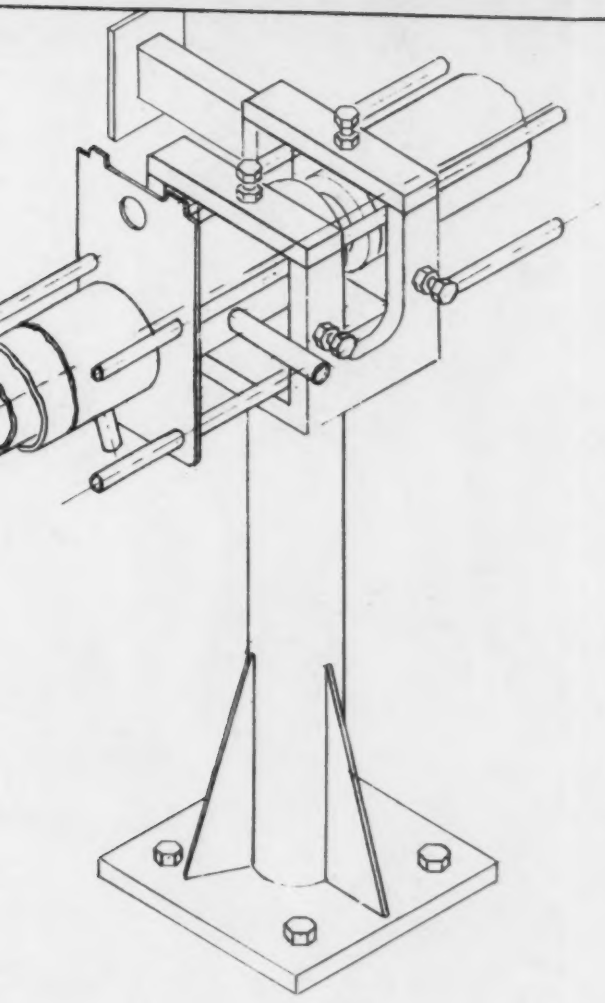
MASTER VACUUM SYSTEM



UM SYSTEM

WILLIAM M. BROBECK & ASSOCIATES 1930 PARK BOULEVARD — OAKLAND 6, CALIFORNIA	
By R. BURLESON Date 6/27/58	Rel. 200-19-D10
For ATOMIC ENERGY COMMISSION	


BEAM

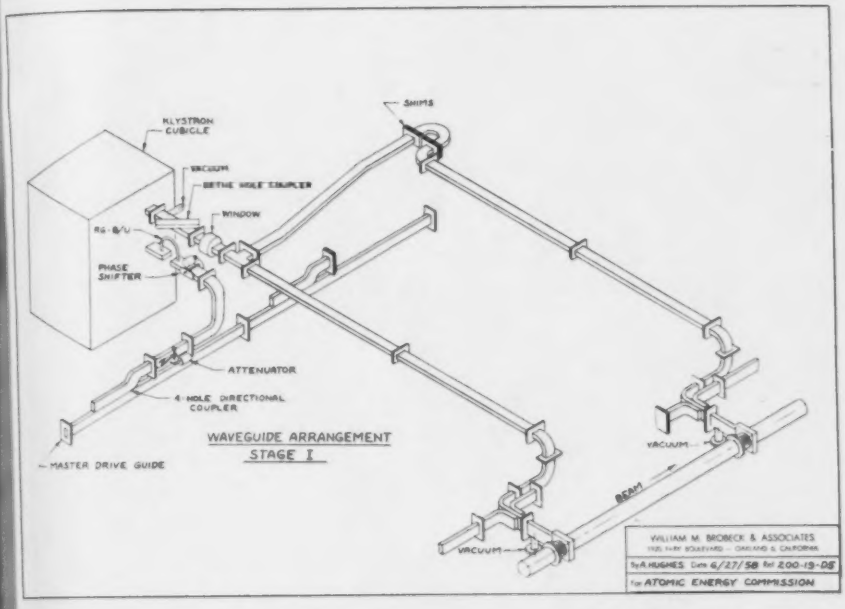


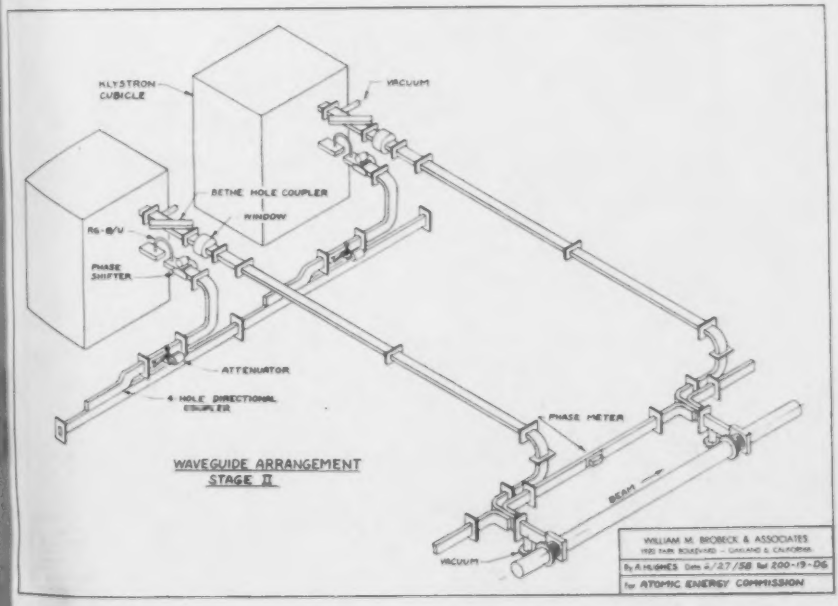
ACCELERATOR TUBE INSTALLATION

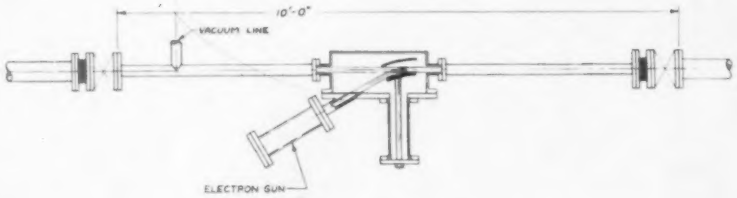
WILLIAM M. BROBECK & ASSOCIATES
1920 PARK BOULEVARD -- OAKLAND 6, CALIFORNIA

By R. BURLEIGH Date 6/28/58 Ref 200-19-D11

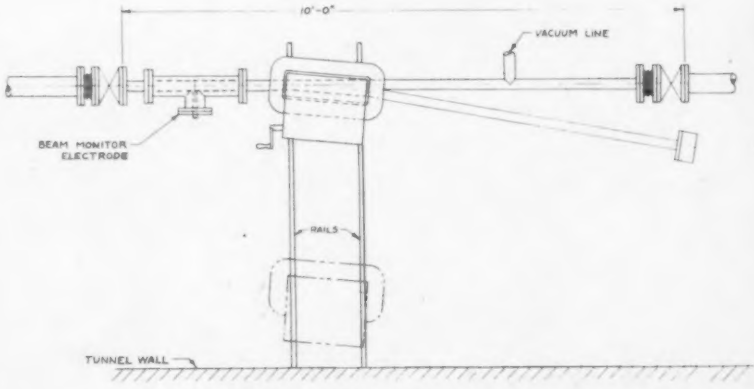
For ATOMIC ENERGY COMMISSION


KLYSTRON CUBICLE
VACUUM
BETHE HOLE COUPLER
WINDOW
RG-8/U
PHASE SHIFTER
ATTENUATOR
4 HOLE DIRECTIONAL COUPLER
MASTER DRIVE GUIDE
SHIMS
VACUUM
BEAM
VACUUM
WAVEGUIDE ARRANGEMENT
STAGE I
WILLIAM M. BROBECK & ASSOCIATES
By A. HUGHES Date 6/27/58 Ref 200-19-D8
for ATOMIC ENERGY COMMISSION


KLYSTRON CUBICLE
VACUUM
BETHE HOLE COUPLER
WINDOW
RG-8/U
PHASE SHIFTER
ATTENUATOR
4 HOLE DIRECTIONAL COUPLER
PHASE METER
BEAM
VACUUM
WAVEGUIDE ARRANGEMENT
STAGE II
WILLIAM M. BROBECK & ASSOCIATES
By A. HUGHES Date 6/27/58 Ref 200-19-D6
for ATOMIC ENERGY COMMISSION



INFLECTOR
IN SECTION 23
SCALE 1" = 1'-0"



DEFLECTOR MAGNET
IN SECTION 25
SCALE 1" = 1'-0"

WILLIAM M. BROBECK & ASSOCIATES
2920 PARK BOULEVARD — OAKLAND 6, CALIFORNIA
By R BURLEIGH Date 6/26/57 Ref 200-19-D12
For ATOMIC ENERGY COMMISSION

DRAWINGS - KAISER

101-C	End Station Area Arrangement Plan
102-C	General Site Plan and Tunnel Profile
101-P	Flow Diagram
102-P	Tunnel Piping Plan
103-P	Tunnel Piping Details
101-S	Tunnel - General Arrangement
102-S	End Station Details
103-S	Tunnel Details
101-E	Electrical Power Single Line Diagram
102-E	Tunnel Wiring Scheme
103-E	Power Layout Outside Tunnel

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PLANT EXPANSION AREA
BENCH ELEV 160
BENCH ELEV 180
180
42"-80'-0" RCP
2-3' GAUGE TRACKS FROM SHOPS & INTERTRON FACTORY TO TUNNEL
EXIST. PAVE MILLED
RELOCATED PAVE MILLED 20' PIT MIS-UNDERGOES LOCATION TO PERMIT FUTURE WIDENING TO FOUR LANES
INTERTRON TUNNEL
ACCELERATOR TUNNEL
EARTH SHIELDING
42"-330' RCP
END OF ACCELERATOR
BEAM SWITCHYARD
120,000 GAL. TURNPIKE WATER STORAGE TANK AT ELEV. 240' FOR FIRE SERVICE

NO.	DATE	REVISION	BY	APP.	APP.

PLAN & PROFILE

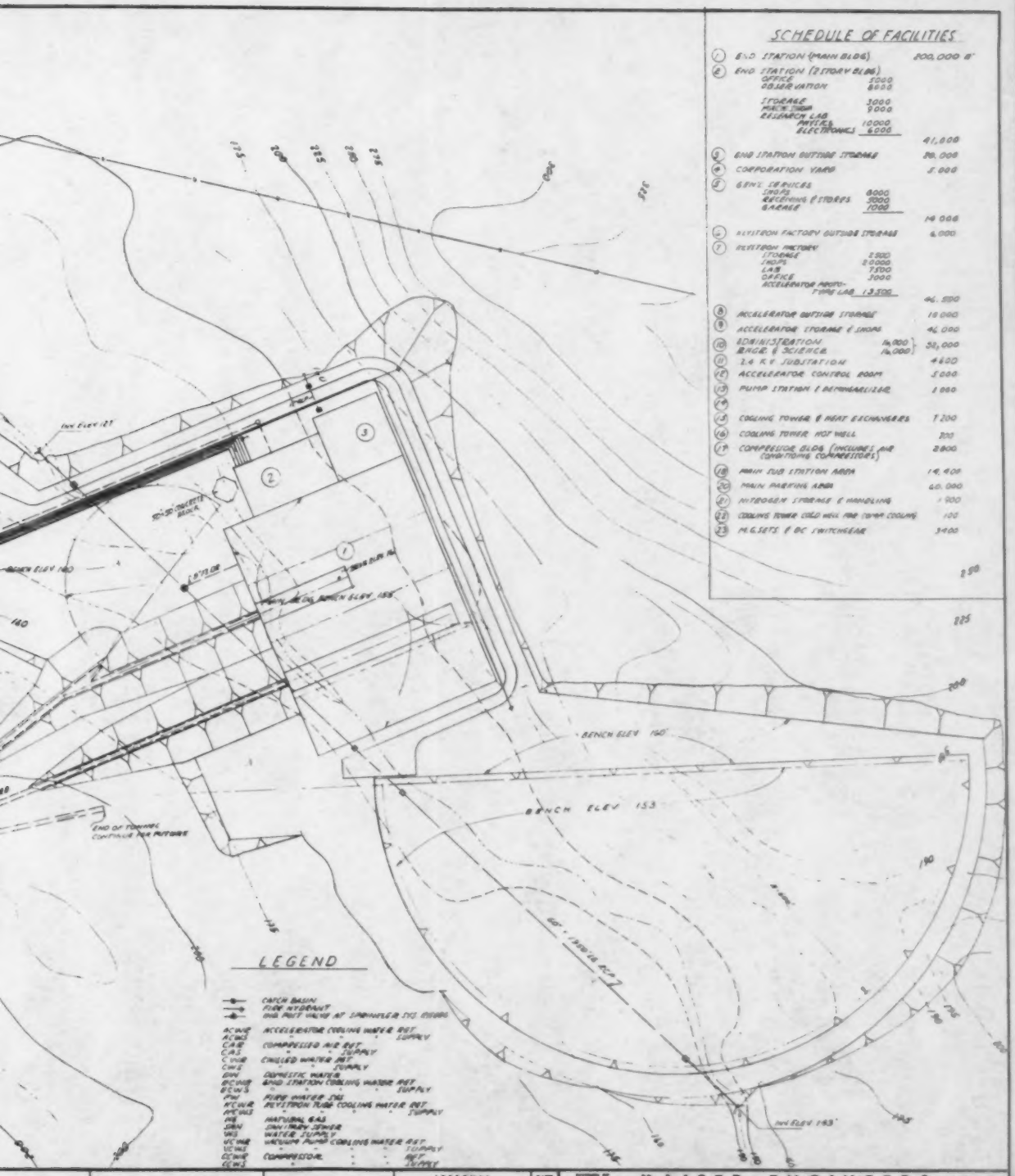
REFERENCE DRAWINGS

ICE-C

NUMBER

NOTES

43633 O - 59 (Page p. 526) No. 1


SCHEDULE OF FACILITIES
1 END STATION (MAIN BLDG.) 200,000 ft²
2 END STATION (2 STORY BLDG.)
OFFICE 5000
OBSERVATION 8000
STORAGE 3000
MACH. SHOP 9000
RESEARCH LAB
PHYSICS 10000
ELECTRONICS 6000
41,000
3 END STATION OUTSIDE STORAGE 20,000
4 CORPORATION YARD 5,000
5 GEN'L SERVICES
SHOPS 8000
RECEIVING & STORES 3000
GARAGE 1000
14,000
6 ELVETRON FACTORY OUTSIDE STORAGE 6,000
7 ELVETRON FACTORY
STORAGE 2,500
SHOPS 20,000
LAB 7,500
OFFICE 3,000
ACCELERATOR PROTOTYPE LAB 13,500
46,500
8 ACCELERATOR OUTSIDE STORAGE 10,000
9 ACCELERATOR STORAGE & SHOPS 46,000
10 ADMINISTRATION 14,000
ENGR. & SCIENCE 38,000 52,000
11 2.4 K.V. SUBSTATION 4620
12 ACCELERATOR CONTROL ROOM 5,000
13 PUMP STATION & DEMINERALIZER 1,000
14
15 COOLING TOWER & HEAT EXCHANGERS 7,200
16 COOLING TOWER HOT WELL 200
17 COMPRESSOR BLDG. (INCLUDES AIR CONDITIONG COMPRESSORS) 2800
18 MAIN SUB STATION AREA 14,400
19 MAIN PARKING AREA 60,000
20 NITROGEN STORAGE & HANDLING 1,900
21 COOLING TOWER COLD WELL FOR TOWER COOLING 100
22 M.G. SETS & DC SWITCHGEAR 3400
BENCH ELEV 160'
BENCH ELEV 153
INV ELEV 193'
60' TRENCH RCP
END OF TUNNEL CONSTRUCTION FOR FUTURE
LEGEND
CATCH BASIN
FIRE HYDRANT
GATE VALVE AT SPRINKLER SYS. RISERS
ACWR ACCELERATOR COOLING WATER RET.
ACWS " " SUPPLY
CAR COMPRESSED AIR RET.
CAS " " SUPPLY
CWR CHILLED WATER RET.
CWS " " SUPPLY
DW DOMESTIC WATER
ECWR END STATION COOLING WATER RET.
ECWS " " " SUPPLY
FW FIRE WATER SYS.
HCWR ELVETRON TUBE COOLING WATER RET.
HCWS " " " SUPPLY
NG NATURAL GAS
SAN SANITARY SEWER
WS WATER SUPPLY
VCWR VACUUM PUMP COOLING WATER RET.
VCWS " " " SUPPLY
CWR COMPRESSOR " RET.
CWS " " SUPPLY

DESCRIPTION	COST ACCOUNT

WORK APPROVED BY THIS DRAWING CHARGED TO COST ACCOUNT ABOVE

CONSTRUCTION APPROVAL

APPROVAL	DATE
PROJECT ENGINEER	
CHIEF ENGINEER	

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DIVISION OF HENRY J. KAISER COMPANY

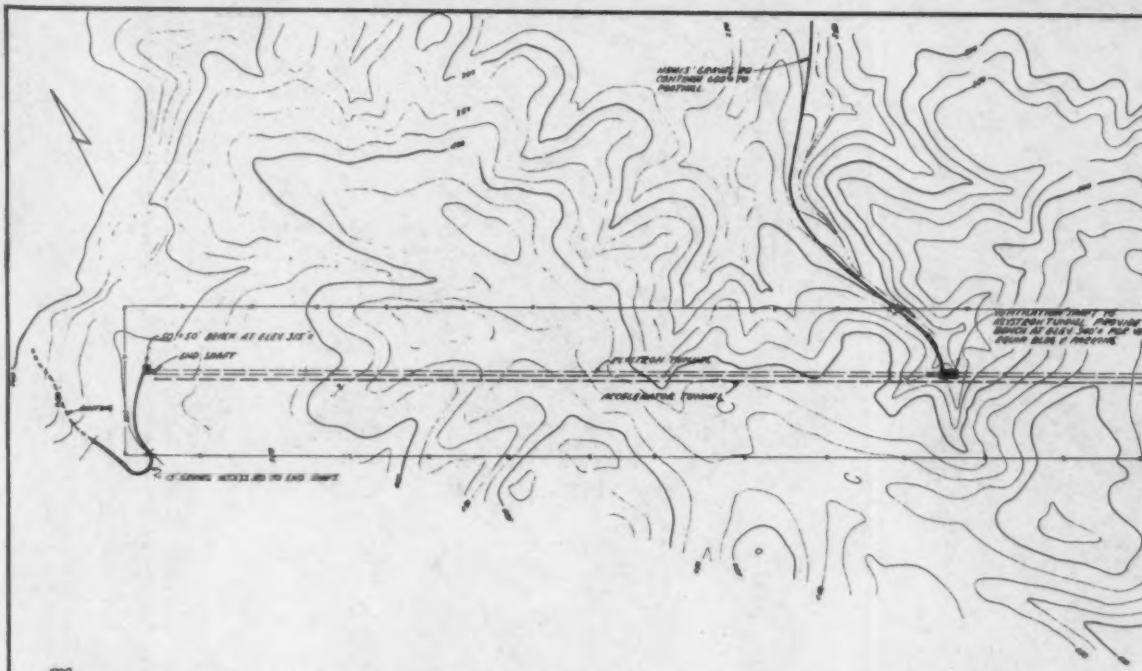
KAISER ENGINEERS OAKLAND, CALIFORNIA

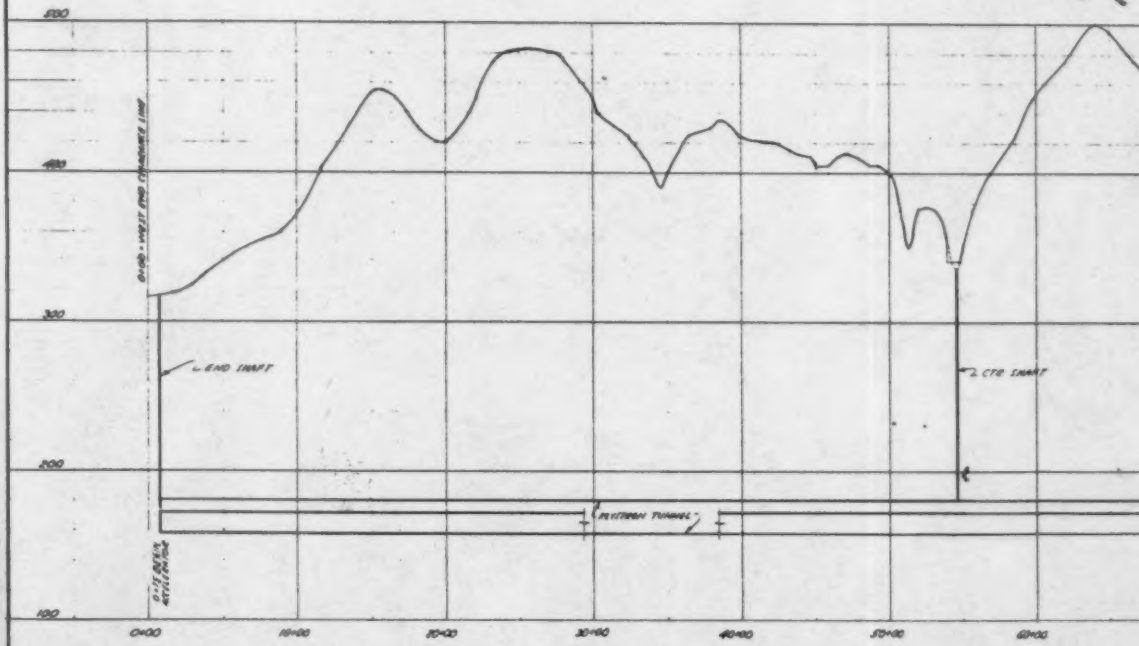
SCALE	1" = 100'
DRAWN BY	RICHWOOD
CHECKED BY	R.W.F.
APPROVED BY	
CHIEF DESIGN ENGINEER	

FOR ATOMIC ENERGY COMMISSION
LOCATION STANFORD UNIVERSITY

TWO MILE LINEAR ELECTRON ACCELERATOR
END STATION AREA ARRANGEMENT PLAN

JOB NO. 5817 DWG. NO. 101-C REV. R-1

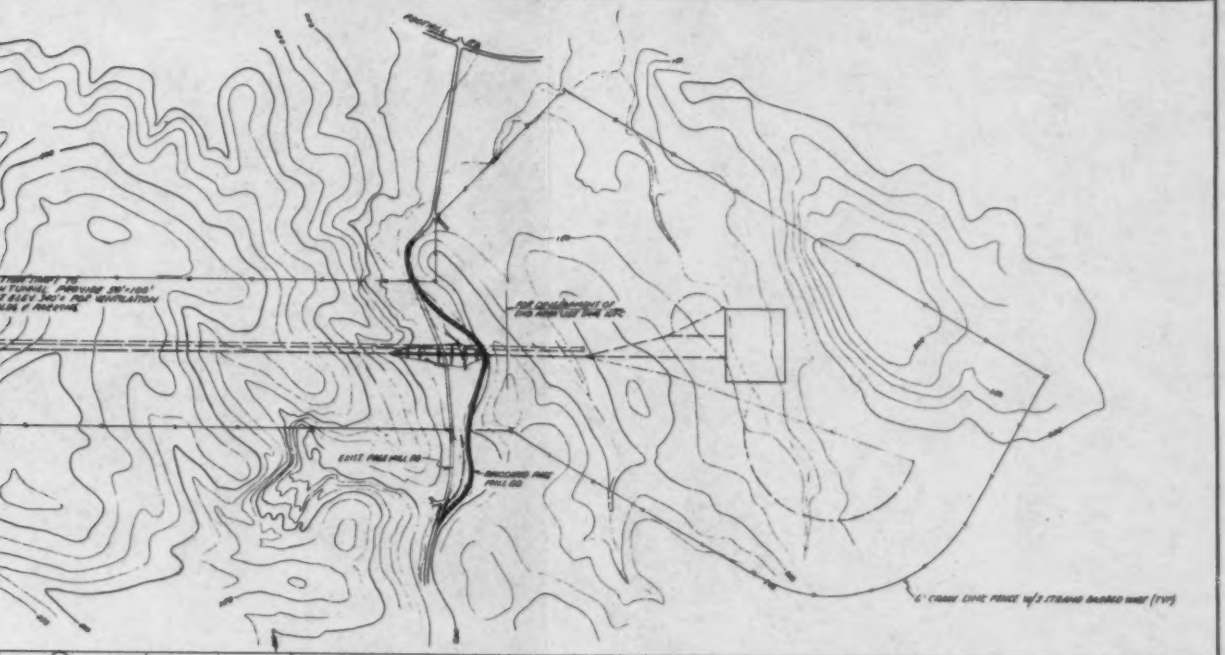


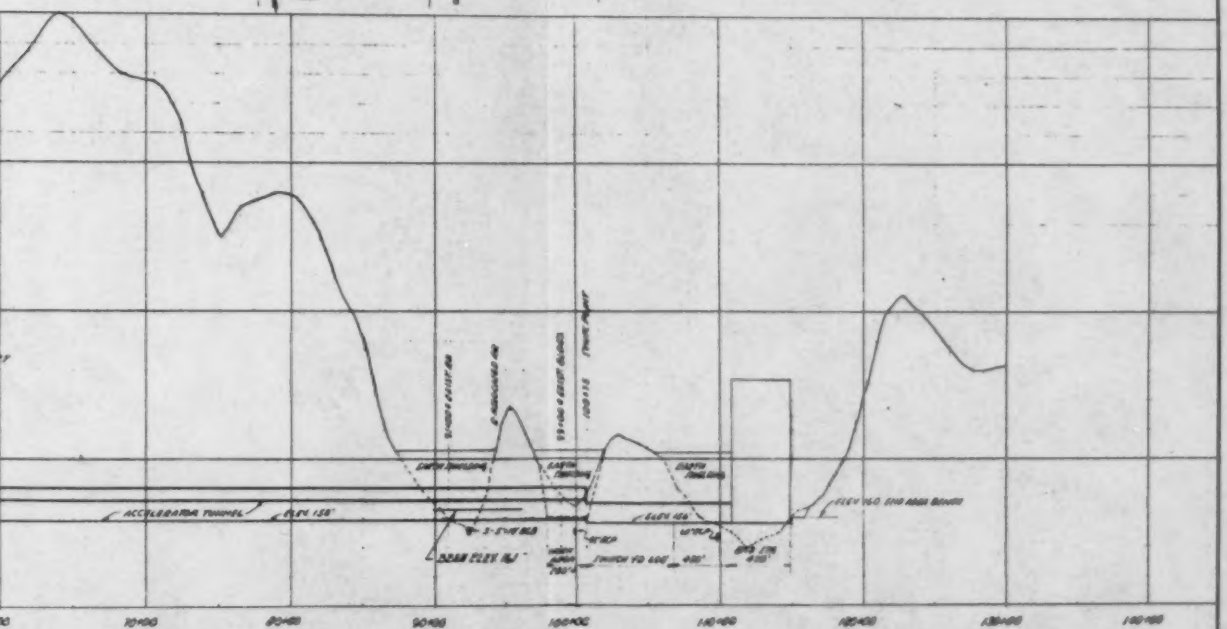


PROFIL

NO.	DATE	REVISION	BY	APP.	APP.	REFERENCE DRAWINGS	NUMBER	NOTES
								1. PROFILE DEVELOPED FROM TUNNELING UNIT REPORT, APRIL 1951. PROJECT C

43633 O - 59 (Face p. 526) No. 2



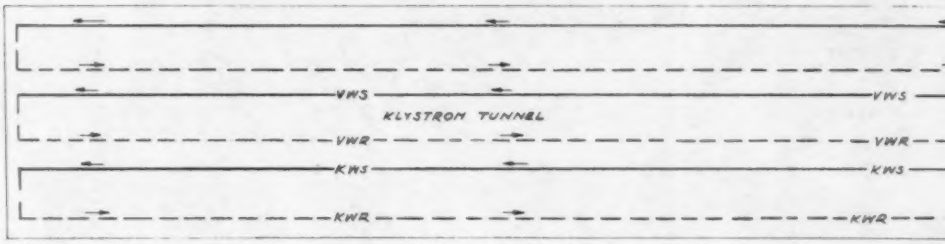


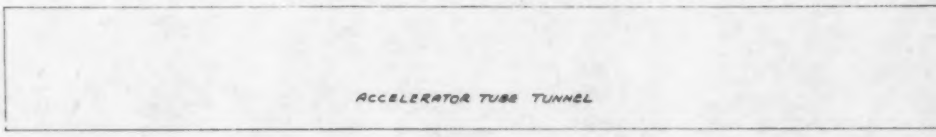
O F I L E

DESCRIPTION	CHK ACCOUNT	WORK REVISED BY THIS DRAWING CHARGED TO CHK ACCOUNT ABOVE	CONSTRUCTION APPROVAL	APPROVAL	DATE	KAISER ENGINEERS
						FOR ATOMIC ENERGY COMMISSION
				CLAS HORTON THOMAS, HEAM & Fr-GO		LOCATION STANFORD UNIVERSITY
				DRAWN BY RWF	7-2-58	TWO MILE LINEAR ELECTRON ACCELERATOR
						GENERAL SITE - PLAN & TUNNEL PROFILE
						JOB NO 5817 DWG. NO 102-C REVISION R-0

LEGEND

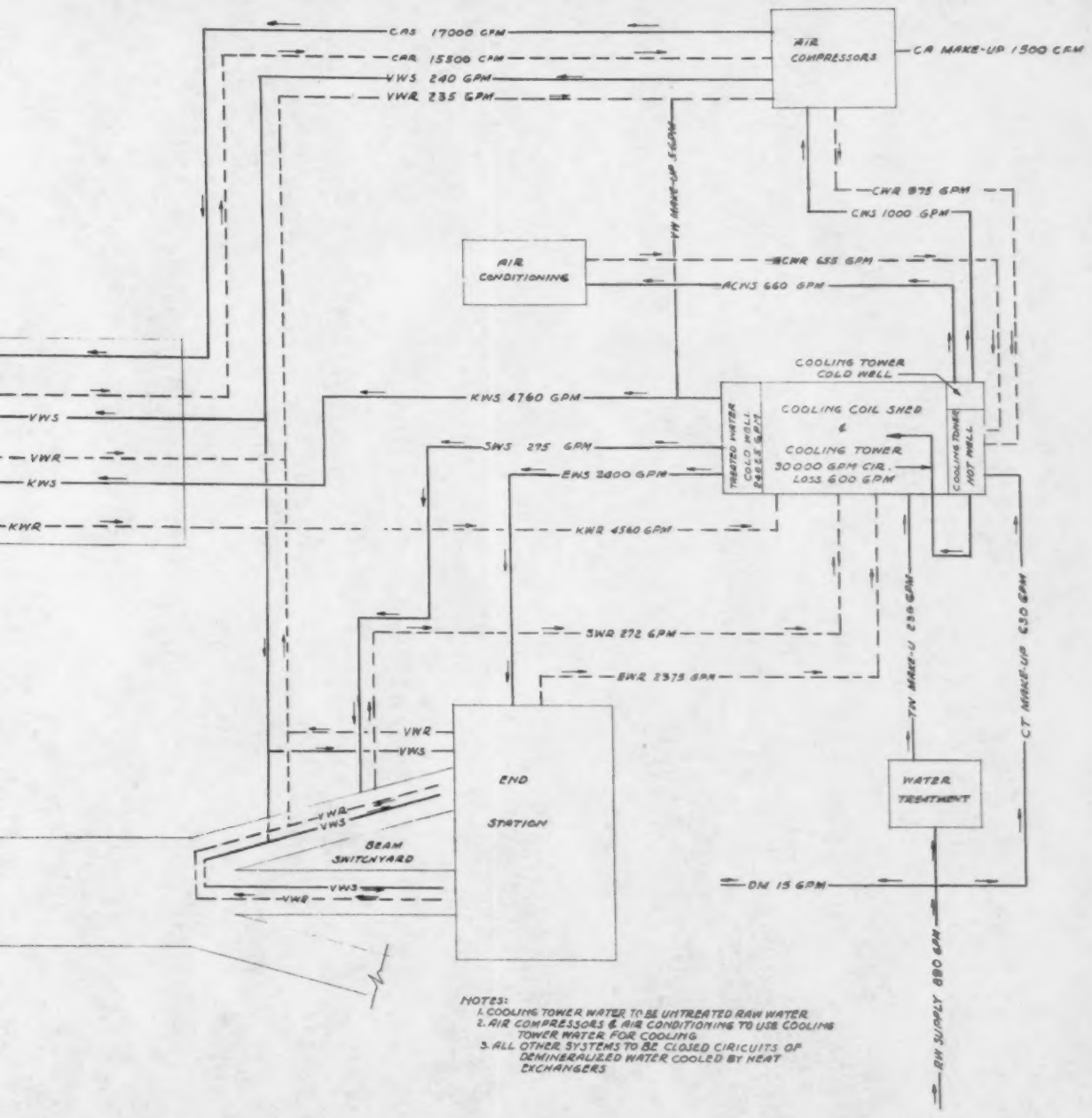
CAS – COMPRESSED AIR SUPPLY
CAR – COMPRESSED AIR RETURN
KWS – KLYSTRON WATER SUPPLY
KWR – " " RETURN
VWS – VACUUM PUMP COOLING WATER SUPPLY
VWR – " " " RETURN
CWS – COMPRESSOR COOLING WATER SUPPLY
CWR – " " " RETURN
ACWS – AIR CONDITIONING COOLING WATER SUPPLY
ACWR – " " " " RETURN
SWS – BEAM SWITCHYARD COOLING WATER SUPPLY
SWR – " " " " RETURN
EWS – END STATION COOLING WATER SUPPLY
EWR – " " " " RETURN
TW – TREATED WATER
DW – DOMESTIC WATER
CT – COOLING TOWER
RW – RAW WATER





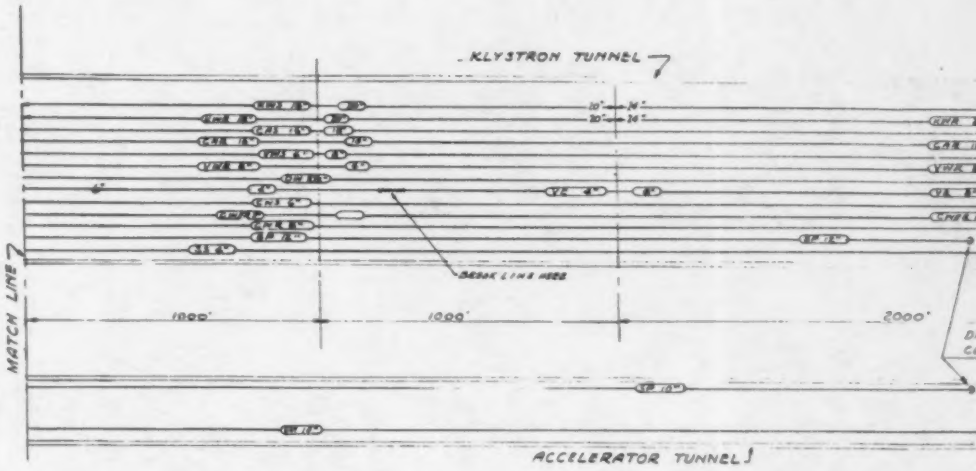
43633 O - 59 (Face p. 526) No. 3

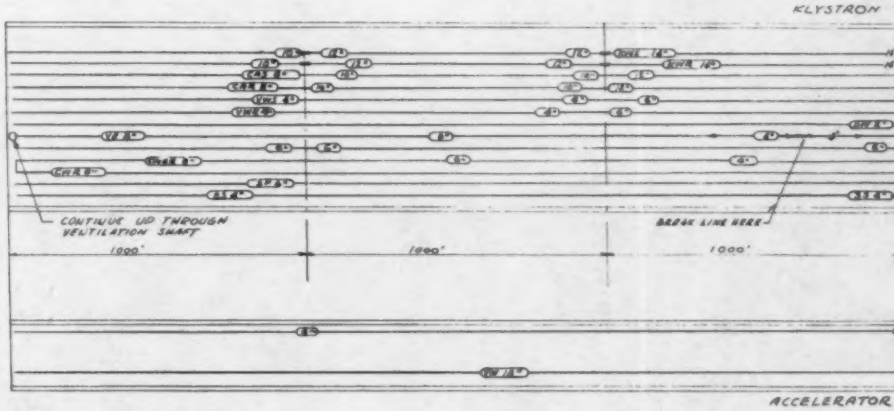
NO.	DATE	REVISION	BY	APP.	APP.	REFERENCE DRAWINGS	NUMBER	NOTES



NOTES:
1. COOLING TOWER WATER TO BE UNTREATED RAW WATER.
2. AIR COMPRESSORS & AIR CONDITIONING TO USE COOLING TOWER WATER FOR COOLING.
3. ALL OTHER SYSTEMS TO BE CLOSED CIRCUITS OF DEMINERALIZED WATER COOLED BY HEAT EXCHANGERS.

DESCRIPTION	COST ACCOUNT	APPROVAL	DATE	KAISER ENGINEERS	
WORK COVERED BY THIS DRAWING CHANGED TO COST ACCOUNT ABOVE	CONSTRUCTION APPROVAL			SCALE NO SCALE	DATE
				DRAWN BY P.L. BISHOP	4/16/58
				CHECKED BY R.W.F.	7/16/58
				APPROVED BY	
				CHIEF ENGINEER	
				FOR ATOMIC ENERGY COMMISSION	
				LOCATION STANFORD UNIVERSITY CALIFORNIA	
				COMPRESSED AIR & WATER FLOW DIAGRAM	
				JOB NO. 5817	DWG. NO. 101-P
					REVISION R-1



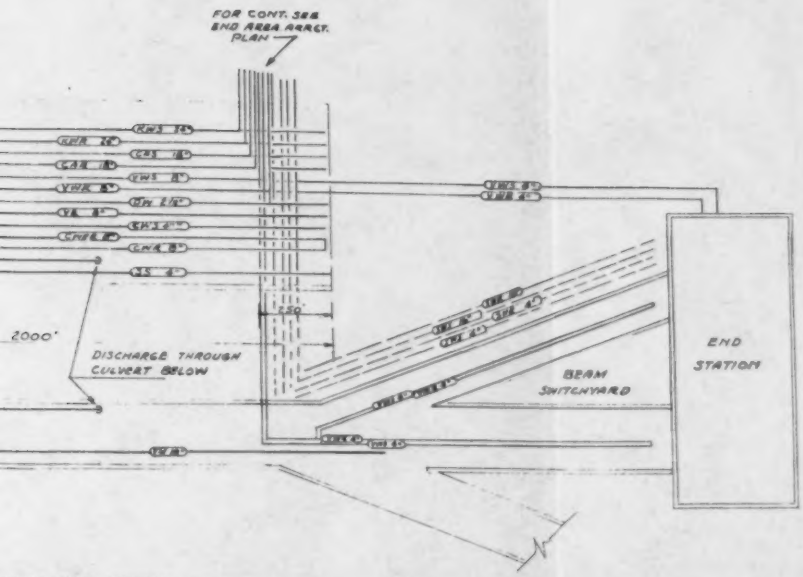


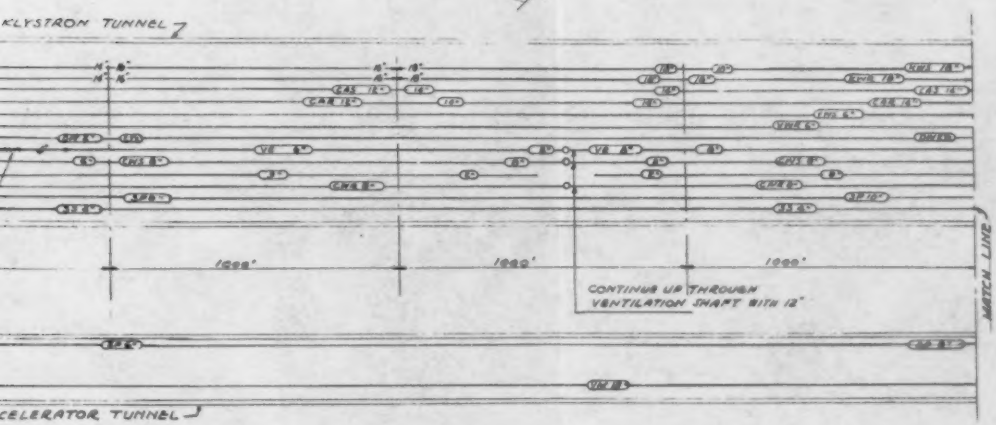
NO.	DATE	REVISION	BY	APP.	APP.	REFERENCE DRAWINGS	NUMBER	NOTES

4633 O - 59 (Face p. 526) No. 4

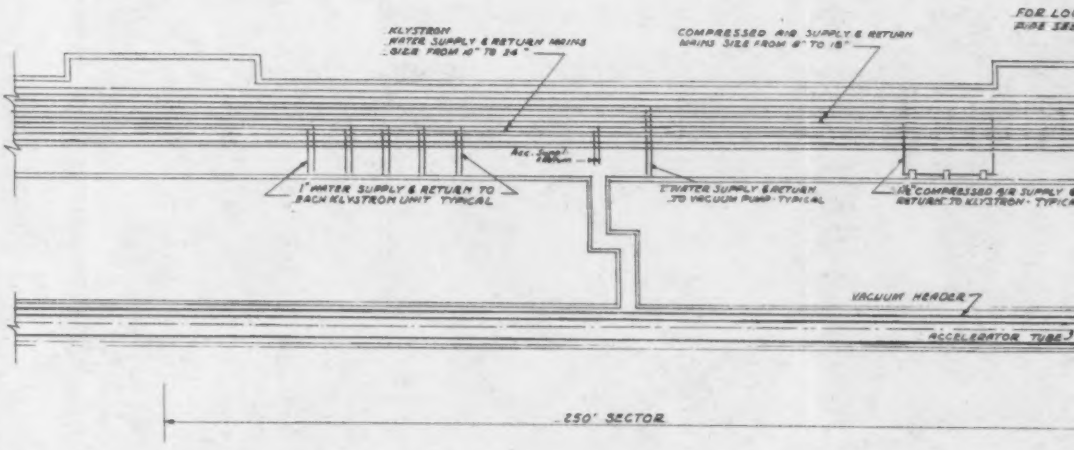
LEGEND

KWS — KLYSTRON COOLING WATER SUPPLY
KWR — KLYSTRON COOLING WATER RETURN
CAS — COMPRESSED AIR SUPPLY
CAR — COMPRESSED AIR RETURN
VWS — VACUUM PUMP COOLING WATER SUPPLY
VWR — VACUUM PUMP COOLING WATER RETURN
DW — DOMESTIC WATER SUPPLY
VE — VACUUM PUMP EXHAUST
CWS — CHILLED WATER SUPPLY
CWER — CHILLED WATER EQUIPMENT RETURN
CWR — CHILLED WATER RETURN
SP — SUMP PUMP PRESSURE MAIN
SS — SANITARY SEWER PRESSURE MAIN
SWS — END STATION & SWITCHYARD COOLING WATER SUPPLY
SWR — END STATION & SWITCHYARD COOLING WATER RETURN
VM — VACUUM MANIFOLD

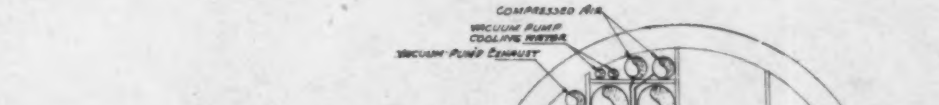




DESCRIPTION	COST ACCOUNT		APPROVAL	DATE	KAISER ENGINEERS
DOES ADDED BY THIS DRAWING CHANGED TO COST ACCOUNT ABOVE	CONSTRUCTION APPROVAL				FOR ATOMIC ENERGY COMMISSION
					LOCATION STANFORD UNIVERSITY, CALIFORNIA
					TWO MILE LINEAR ELECTRON ACCELERATOR
					TUNNEL PIPING PLAN
					JOB NO. 5817 DWG. NO. 102-P REVISION R-1



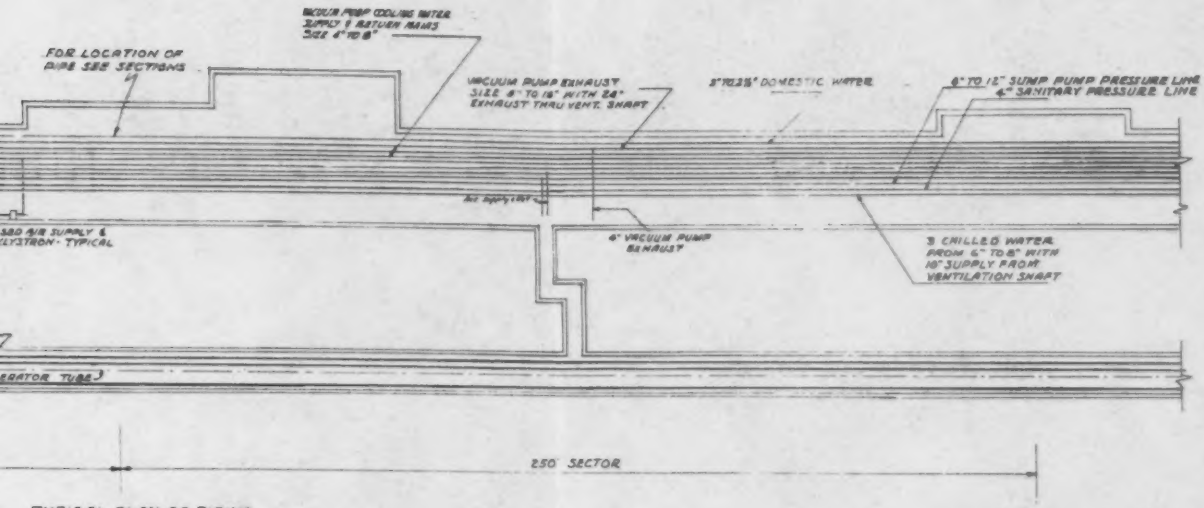
TYPICAL



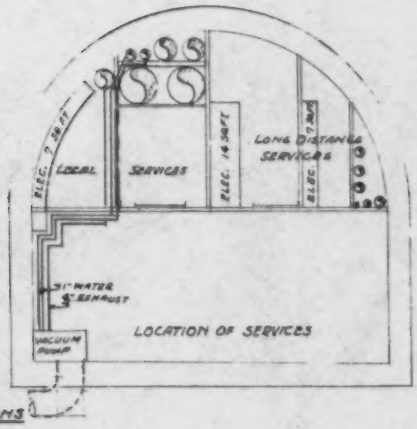
TUNNEL PIPING SECTIONS

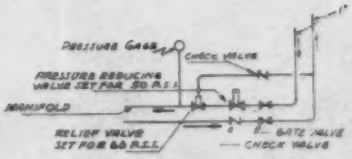
NO.	DATE	REVISION	BY	APP.	APP.	REFERENCE DRAWINGS	NUMBER	NOTES

43633 O - 59 (Face p. 526) No. 5

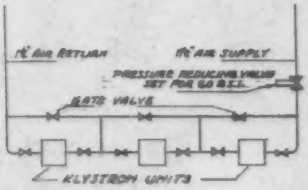

FOR LOCATION OF PIPE SEE SECTIONS
VACUUM PUMP EXHAUST SIZE 8" TO 16" WITH 24" EXHAUST THRU VENT. SHAFT
3"ø 3½" DOMESTIC WATER
6" TO 12" SUMP PUMP PRESSURE LINE
4" SANITARY PRESSURE LINE
4" VACUUM PUMP EXHAUST
3 CHILLED WATER FROM 6" TO 8" WITH 10" SUPPLY FROM VENTILATION SHAFT
250 SECTOR

TYPICAL PLAN OF PIPING

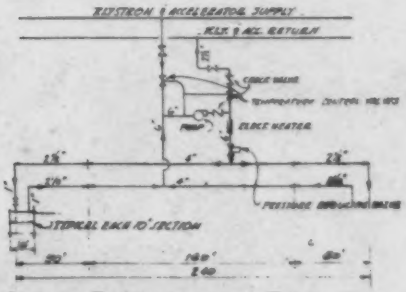




WATER PIPING TO KLYSTRONS

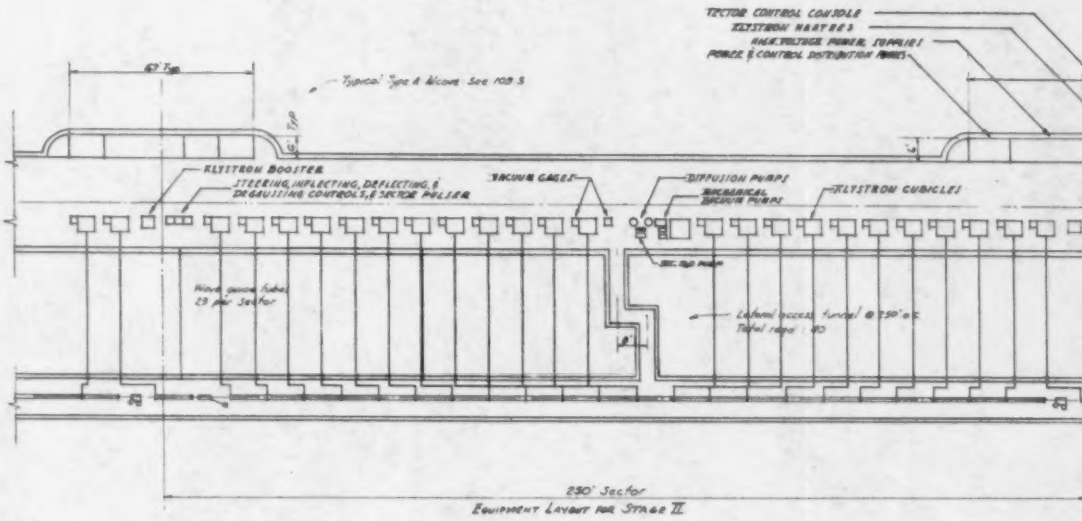


AIR PIPING TO KLYSTRONS



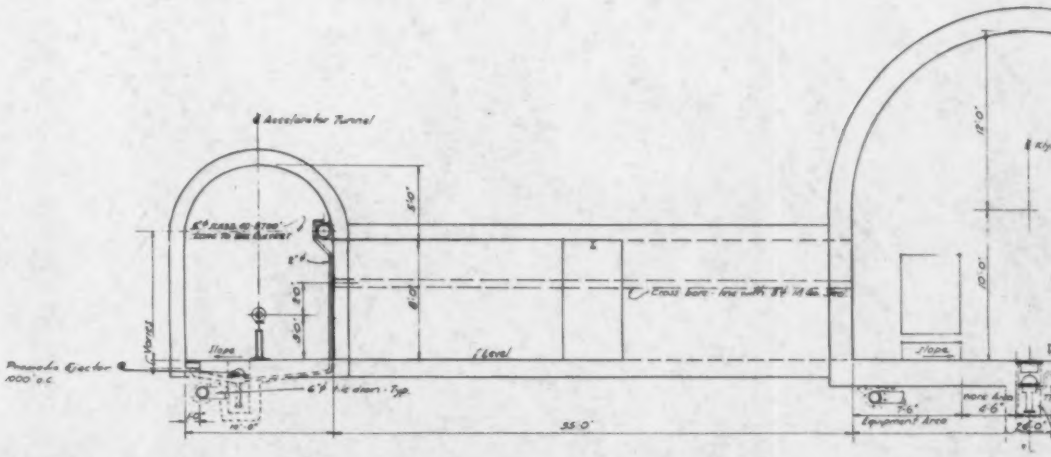
PIPING TO ACCELERATOR TUBE

		APPROVAL	DATE	KAISER ENGINEERS	
				DRAWN R.L. BISHOP 8/14/58	FOR ATOMIC ENERGY COMMISSION
				CHECKED R.W.F. 8/14/58	LOCATION STANFORD UNIVERSITY CALIFORNIA
					TWO MILE LINEAR ELECTRON ACCELERATOR TUNNEL PIPING DETAILS
DESCRIPTION	COST ACCOUNT	CONSTRUCTION APPROVAL		JOB NO. 5817	DWG. NO. 103-P R-1



EQUIPMENT LAYOUT FOR STAGE II

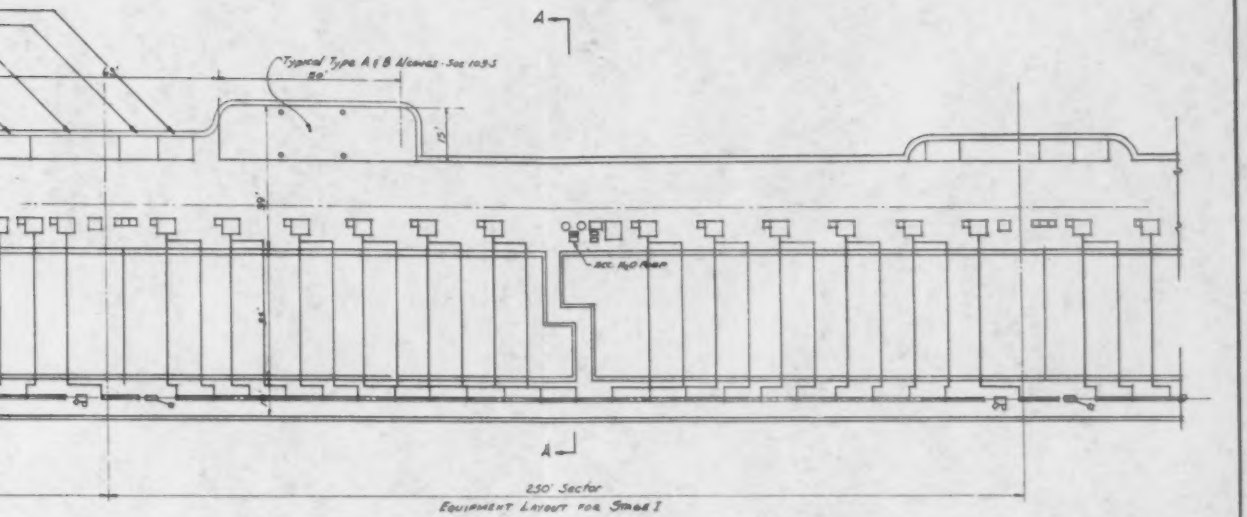
TYPICA



SECTION A

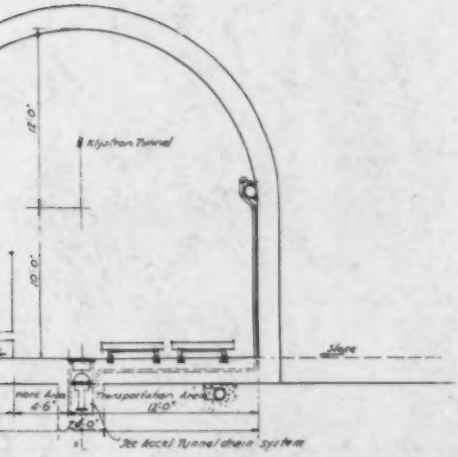
NO.	DATE	REVISION	BY	APP.	APP.	REFERENCE DRAWINGS	NUMBER	NOTES

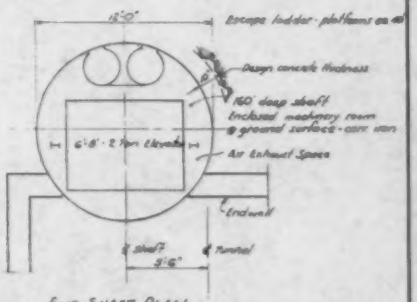
43(33 O - 59 (Face p. 526) No. 6



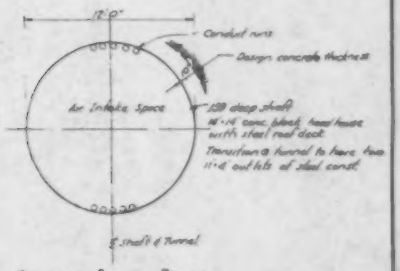
EQUIPMENT LAYOUT FOR STAGE I

TYPICAL PLAN





END SHAFT PLAN


17'-0"
Conduit runs
Design concrete thickness
Air Intake Space
150 deep shaft
18'-10" conc. lined head house with steel roof deck
Transition @ tunnel to have two 11'-0 cut lots of steel const.
℄ Shaft ℄ Tunnel

CENTER SHAFT PLAN

DESCRIPTION	COST ACCOUNT	WORK REVISED BY THIS DRAWING CHARGED TO COST ACCOUNT ABOVE	CONSTRUCTION APPROVAL	APPROVAL	DATE

KAISER ENGINEERS — OAKLAND, CALIFORNIA

SCALE 1"=10'-0" & 2"=1'-0" — DATE
DRAWN E. F. Nielsen — 6-10-57
DESIGNED RWE — 7-3-57
APPROVED — 7/8/57
COST ESTIMATE
CHIEF ENGINEER

FOR ATOMIC ENERGY COMMISSION
LOCATION STANFORD UNIVERSITY, CALIFORNIA

TWO MILE LINEAR ELECTRON ACCELERATOR TUNNEL — GENERAL ARRANGEMENT

JOB NO. 5817 | DWG. NO. 101-S | REV. R-1

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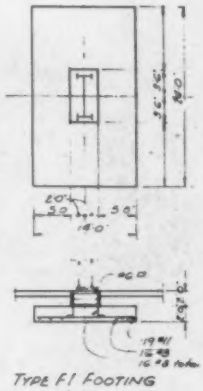
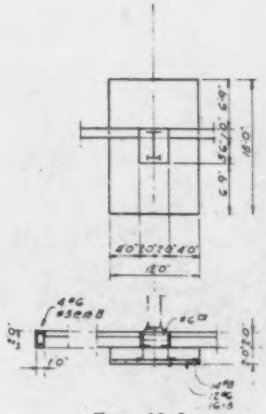
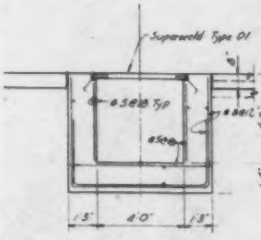


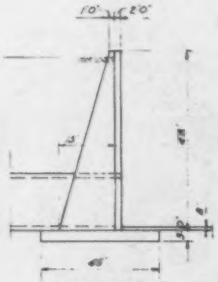
TYPE F1 FOOTING
3/8"=1'-0"



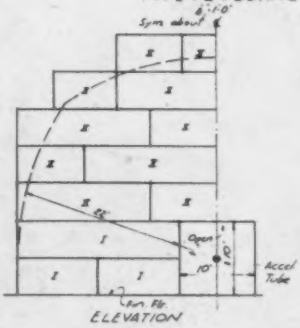
TYPE F2 FOOTING
3/8"=1'-0"



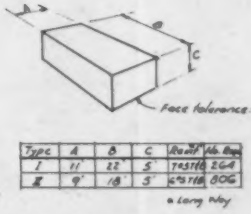
SECTION A
Typical Trench
3/8"=1'-0"



SECTION B
3/8"=1'-0"



ELEVATION

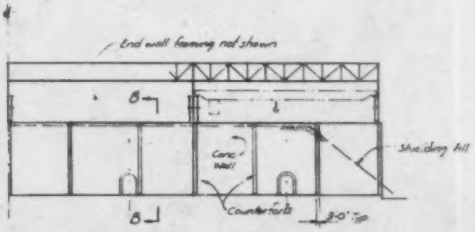


Type	A	B	C	Reqd	Mk Req
I	11'	22'	5'	TASTEE EGG	
II	9'	18'	5'	TASTEE BOG	

a Long Way

SHIELDING BLOCK DETAILS
No Scale

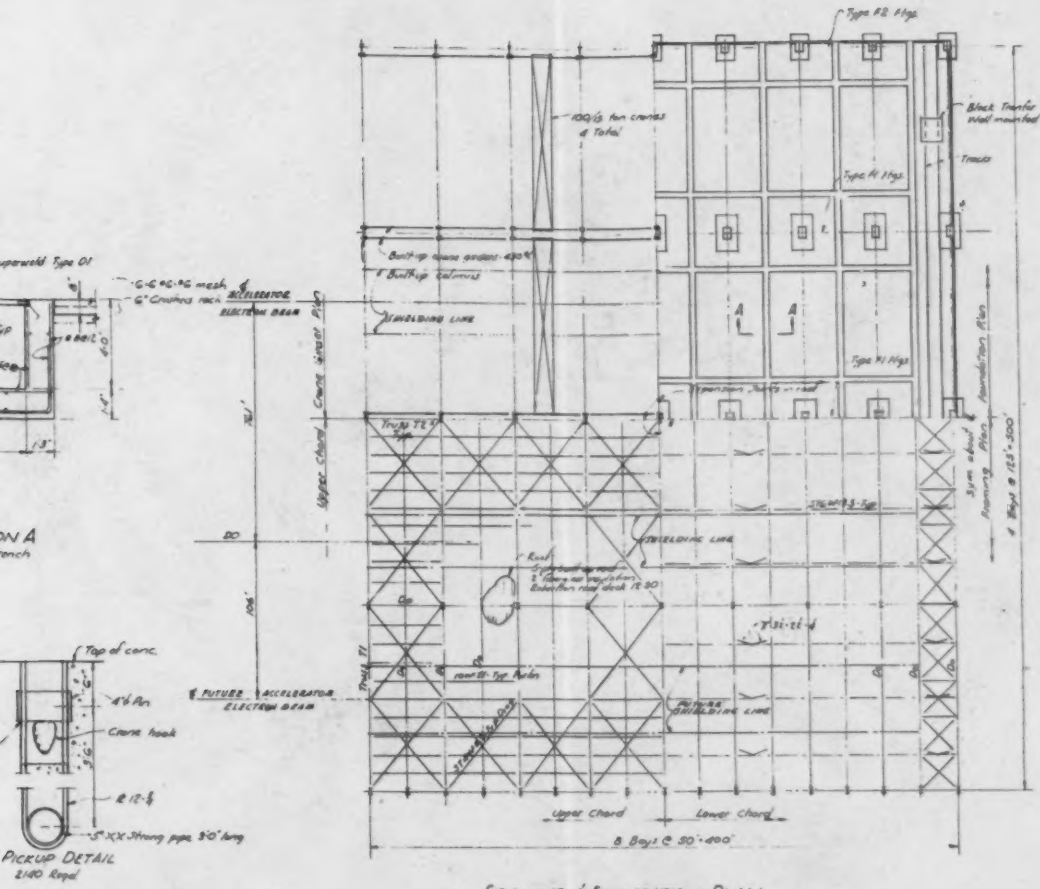
PICKUP DETA
2140 Reqd



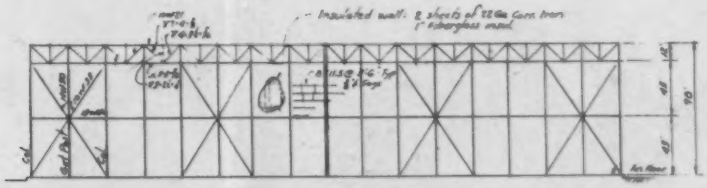
WEST ELEVATION
1"=40'

NO.	DATE	REVISION	BY	APP.	APP.	REFERENCE DRAWINGS	NUMBER	NOTES

43633 O - 59 (Face p. 526) No. 7

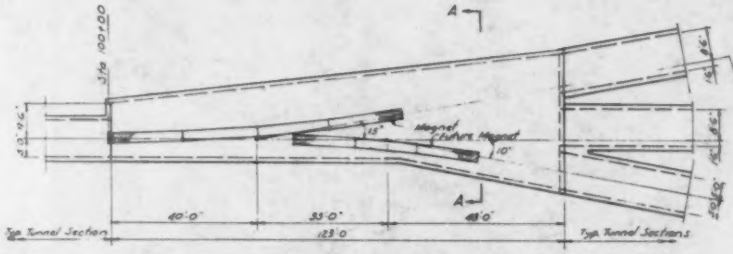


FRAMING & FOUNDATION PLAN
1"-40'

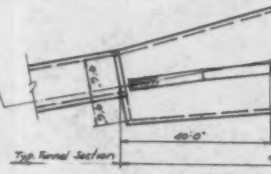


SOUTH ELEVATION
1"-40'

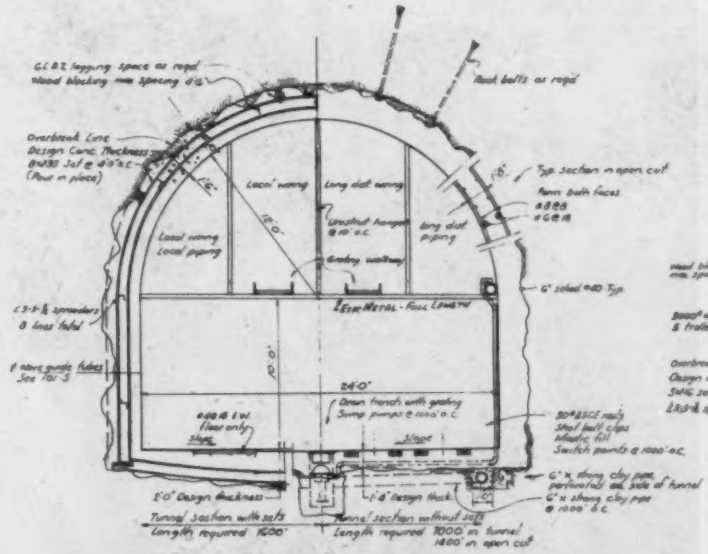
DESCRIPTION	COST ACCOUNT	APPROVAL	DATE	KAISER ENGINEERS	OAKLAND CALIFORNIA
WORK COVERED BY THIS DRAWING CHARGED TO COST ACCOUNT ABOVE	CONSTRUCTION APPROVAL			SCALE Noted DRAWN BY E.F. Nielsen 6-6-50 CHECKED BY R.W.F. 7-5-50	FOR Atomic Energy Commission LOCATION Stanford University, California
					TWO MILE LINEAR ELECTRON ACCELERATOR END STATION DETAILS
					JOB NO. 5817 DWG. NO. 102 S REVISIONS R-1



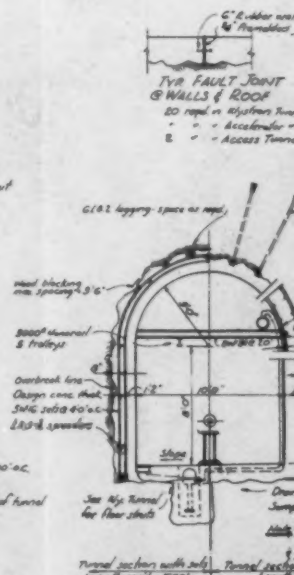
SWITCHYARD TUNNEL PLAN
Station 100+00



SWITCHYAR
Stati



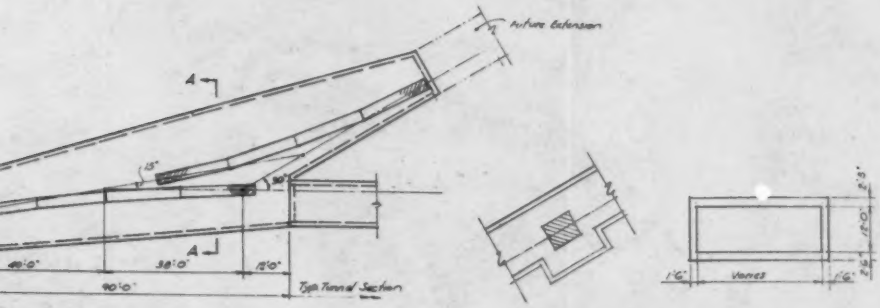
KLYSTRON TUNNEL DETAILS
Total Length - 10,000 feet



ACCELERATOR TUNNEL DET
Total Length of Tunnels 12,100

NO.	DATE	REVISION	BY	APP.	APP.	REFERENCE DRAWINGS	NUMBER	NOTES

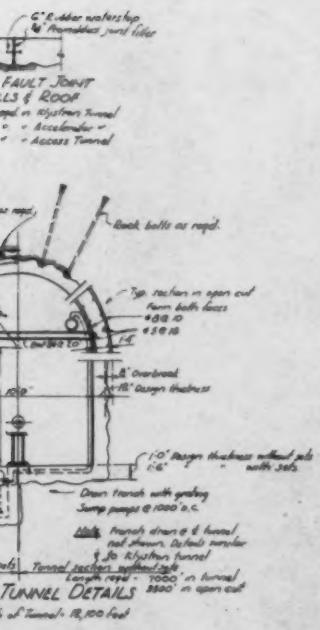
43633 O - 59 (Face p. 526) No. 8

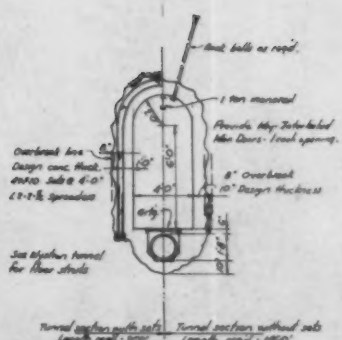


TYPICAL FOR QUADRUPOLE MAG.

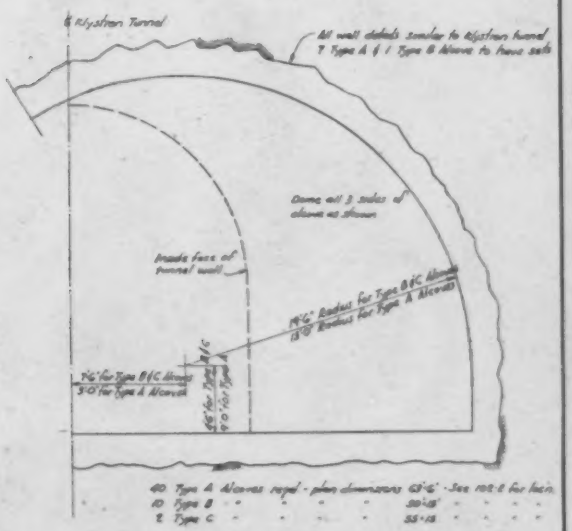
SWITCHYARD TUNNEL PLAN
Station 106+00 ±

SECTION A



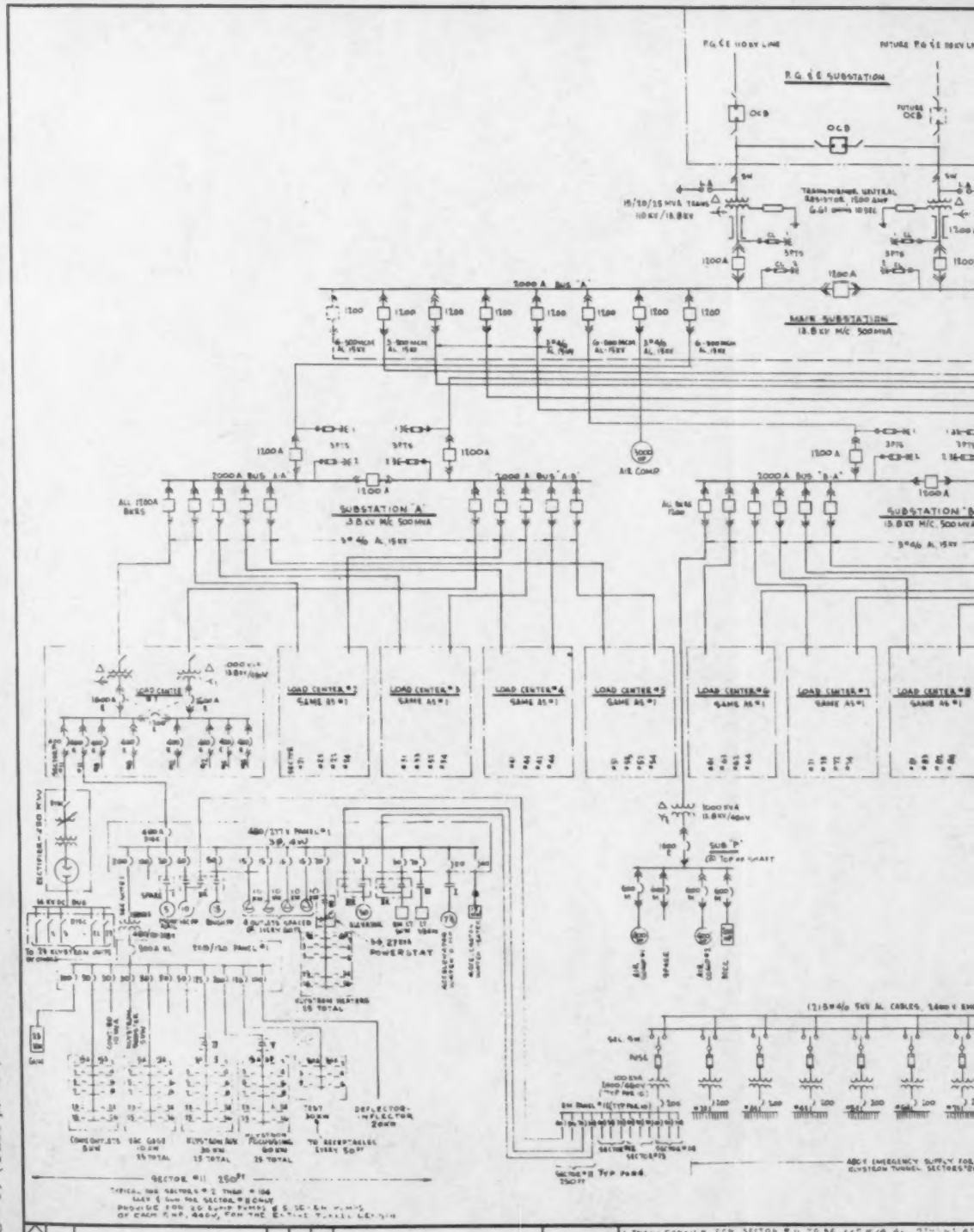


PERSONNEL ACCESS TUNNEL DETAILS
Total Length of Tunnel = 1720'


℄ Klystron Tunnel
All wall details similar to Klystron tunnel
7 Type A & 1 Type B Alcoves to have pads
Dome all 3 sides of
alcoves as shown
Inside face of
tunnel wall
15'6" Radius for Type B & C Alcoves
13'0" Radius for Type A Alcoves
1'6" for Type B & C Alcoves
3'0" for Type A Alcoves
4'6" for Type A
9'0" for Type A
40 Type A Alcoves repl - plan dimensions 13'6" - See 102.1 for basis
10 Type B " " " " 20'6" " " " "
2 Type C " " " " 55'1½ " " " "

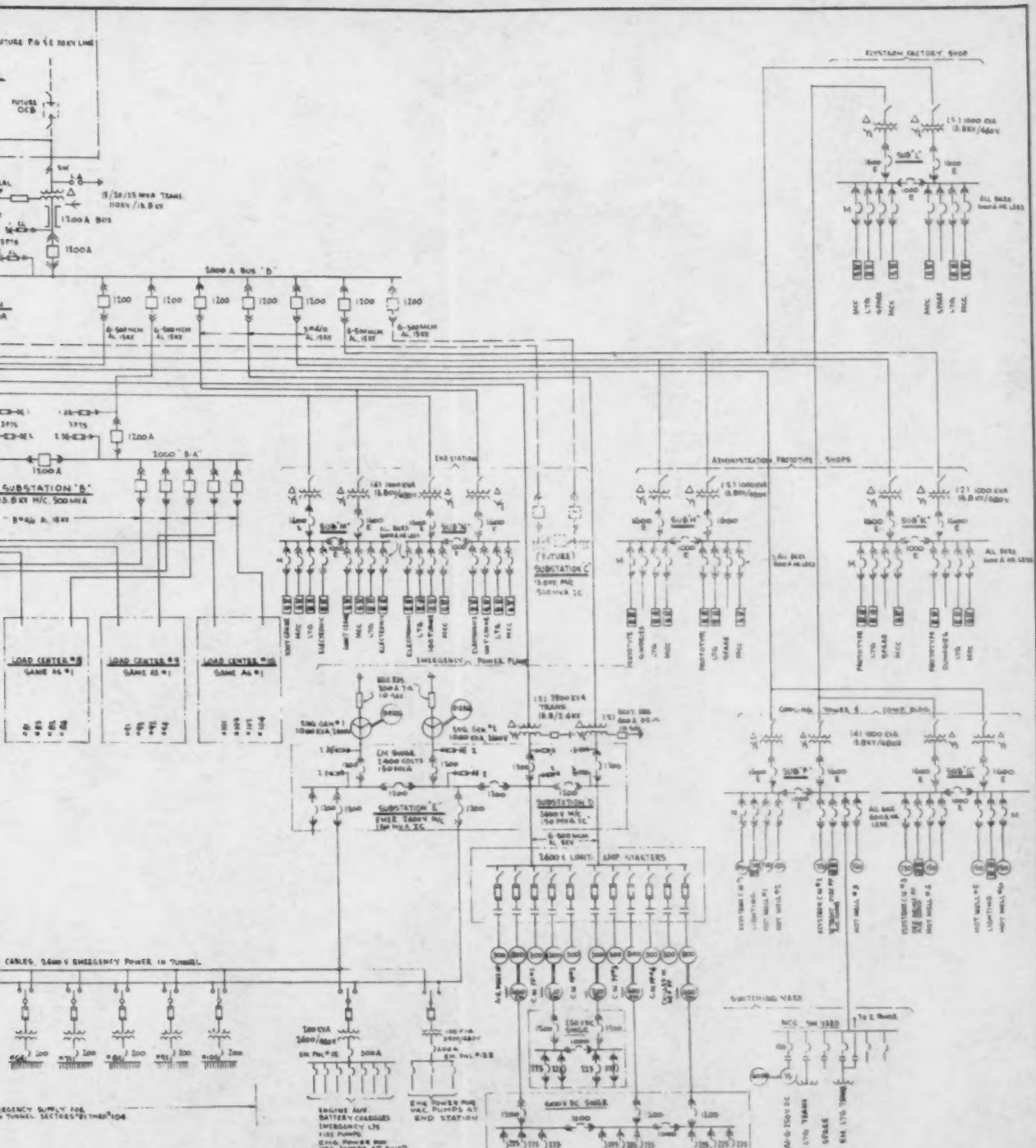
TYPICAL SECTION & ALCOVES

DESCRIPTION	COST ACCOUNT	WORK COVERED BY THIS DRAWING CHARGED TO COST ACCOUNT ABOVE	CONSTRUCTION APPROVAL	APPROVAL	DATE	KAISER ENGINEERS — OAKLAND, CALIFORNIA
				DRAWN E. Nielsen	6-20-58	FOR ATOMIC ENERGY COMMISSION
				DESIGNED R.W.F.	7-3-58	LOCATION STANFORD UNIVERSITY, CALIFORNIA
				PROJECT ENGINEER	7/16/58	TWO MILE LINEAR ELECTRON ACCELERATOR TUNNEL DETAILS
				CHIEF ENGINEER		JOB NO. 5817 DWG. NO. 103-S REVISION R-1

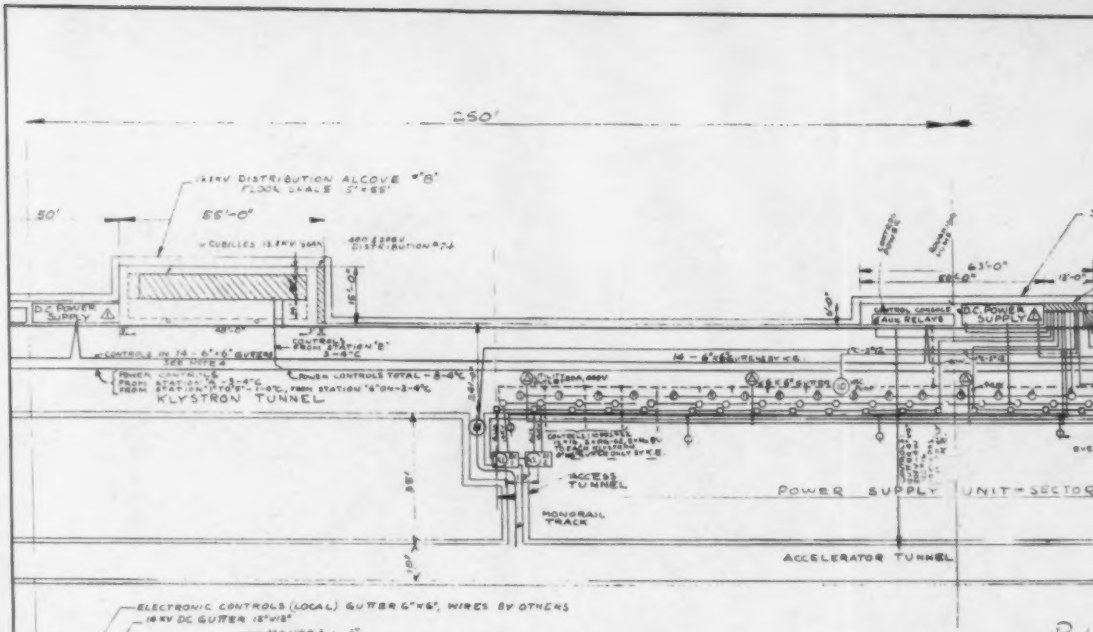


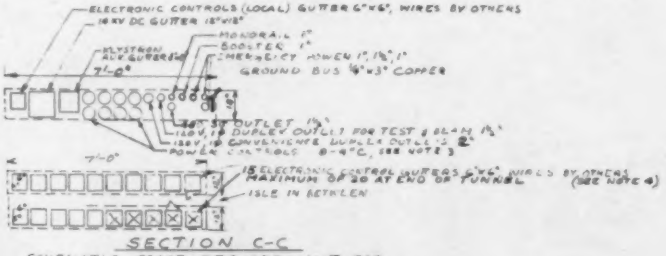
43633 O – 59 (Face p. 526) No. 9

NO.	DATE	REVISION	BY	APP.	APP	REFERENCE DRAWINGS	NUMBER	NOTES



DESCRIPTION	COST ACCOUNT	CONSTRUCTION APPROVAL	APPROVAL	DATE	KAISER ENGINEERS
					FOR ATOMIC ENERGY COMMISSION
					LOCATION STANFORD UNIVERSITY, CALIF.
					TWO MILE LINEAR ELECTRON ACCELERATOR
					ELECTRICAL POWER SINGLE LINE DIAGRAM
					JOB NO. 5817 DWG. NO. 101-E REVISION R-1




ELECTRONIC CONTROLS (LOCAL) GUTTER 6"x6", WIRES BY OTHERS
16 KV DC GUTTER 18"x18"
MONORAIL 1"
BOOSTER 1"
EMERGENCY POWER 1", 1½", 1"
GROUND BUS ¼"x3" COPPER
KLYSTRON ALV GUTTER 24"
7'-0"
20 AMP OUTLET ½"
120 V, 1Ø DUPLEX OUTLET FOR TEST & ALARM ½"
120 V, 1Ø CONVENIENCE DUPLEX OUTLETS 2"
POWER CONTROLS 0-4°C, SEE NOTE 3
7'-0"
15 ELECTRONIC CONTROL GUTTERS 6"x6" WIRED BY OTHERS
MAXIMUM OF 20 AT END OF TUNNEL (SEE NOTE 4)
ISLE IN KETHLEN

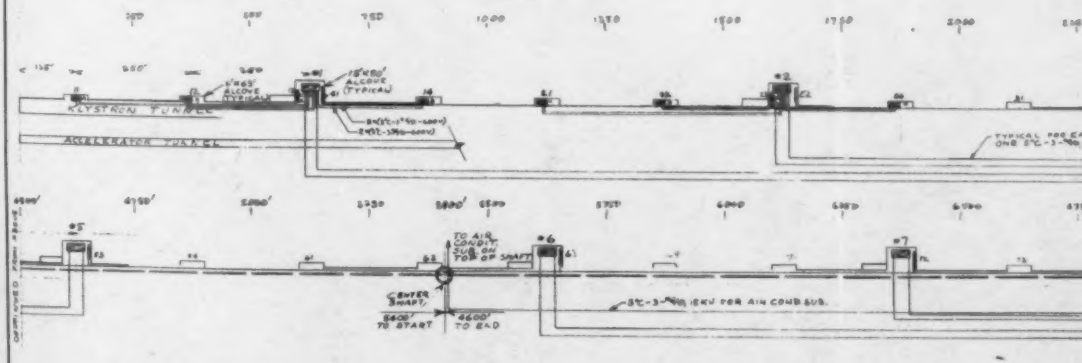
SECTION C-C

SCHEMATIC SPACE REQUIREMENT FOR CONTROL, AUXILIARY & SUPERVISORY CONDUITS & GUTTERS
NTS

PL

TWO SECTORS OF

LONG DISTAN
NT
SEE



PLAN

SUBSTATION LAY

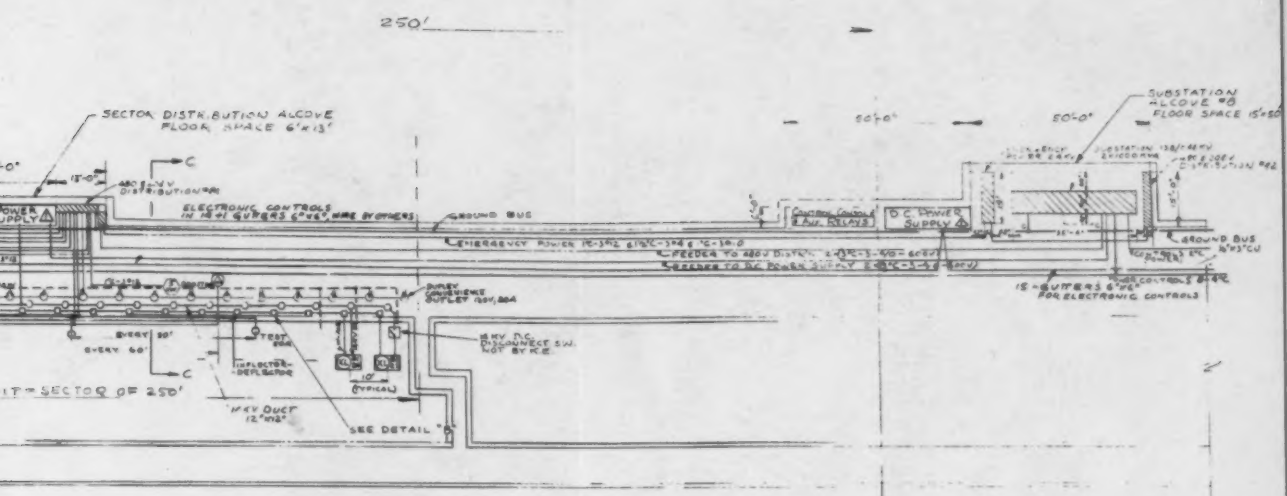
NTS
SEE NOT

NO.	DATE	REVISION	BY	APP.	APP.	REFERENCE DRAWINGS	NUMBER

NOTES

1. LIGHTING WIRING IS NOT SHOWN
2. ALL WIRING IS INDICATED SCHEMATICALLY
3. CONTROL WIRES ORIGINATING IN STATION "B" — 13-¾"
DIRECTLY MATING IN STATION "B" - 18-¾" CABLES
DIRECTLY ORIGINATING IN EACH OF
THE SUBSTATIONS # 1 TO 10
4-¾" CABLES
4. ELECTRONIC CONTROL WIRE GUTTER 6"x6" ORIGINATES IN
SECOND SECTOR SUBSTATION, TOTALING 20 GUTTERS

43633 O - 59 (Face p. 526) No. 10



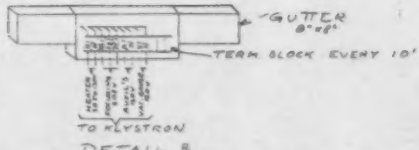
PLAN

RS OF 250' EACH WITH LOCAL WIRING

DISTANCE POWER WIRING NOT SHOWN

NTS

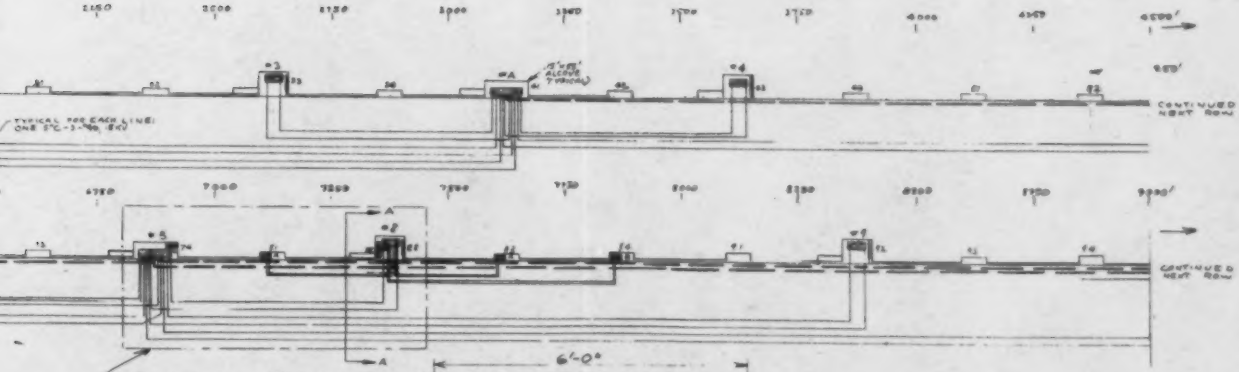
SEE NOTES 1 & 2

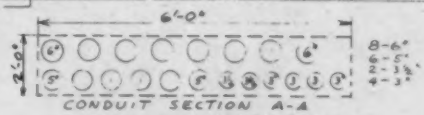


DETAIL B

SCHEMATIC WIRING TO KLYSTRON

NTS





CONDUIT SECTION A-A

SCHEMATIC SPACE REQUIREMENT

FOR LONG DISTANCE POWER ONLY

NTS

PLAN

ION LAYOUT IN TUNNEL

NTS

SEE NOTE 2

CALLY

ON "A" — 1/2-1/2 CABLES

CABLES 2-1/2" "

" 2-3/4" "

" 8-1/2" "

ORIGINATES IN EVERY

60 GUTTERS 6"x6"

DESCRIPTION	COST ACCOUNT

WORK COVERED BY THIS DRAWING CHARGED TO COST ACCOUNT ABOVE

CONSTRUCTION APPROVAL

APPROVAL	DATE

KAISER ENGINEERS

SCALE	NONE
DRAWN BY	M.A. Lewis 6-22-56
CHECKED BY	Mann 9-20-56
PROJECT ENGINEER	Barbara 9/26
APPROVED BY	
CHIEF DESIGNER	

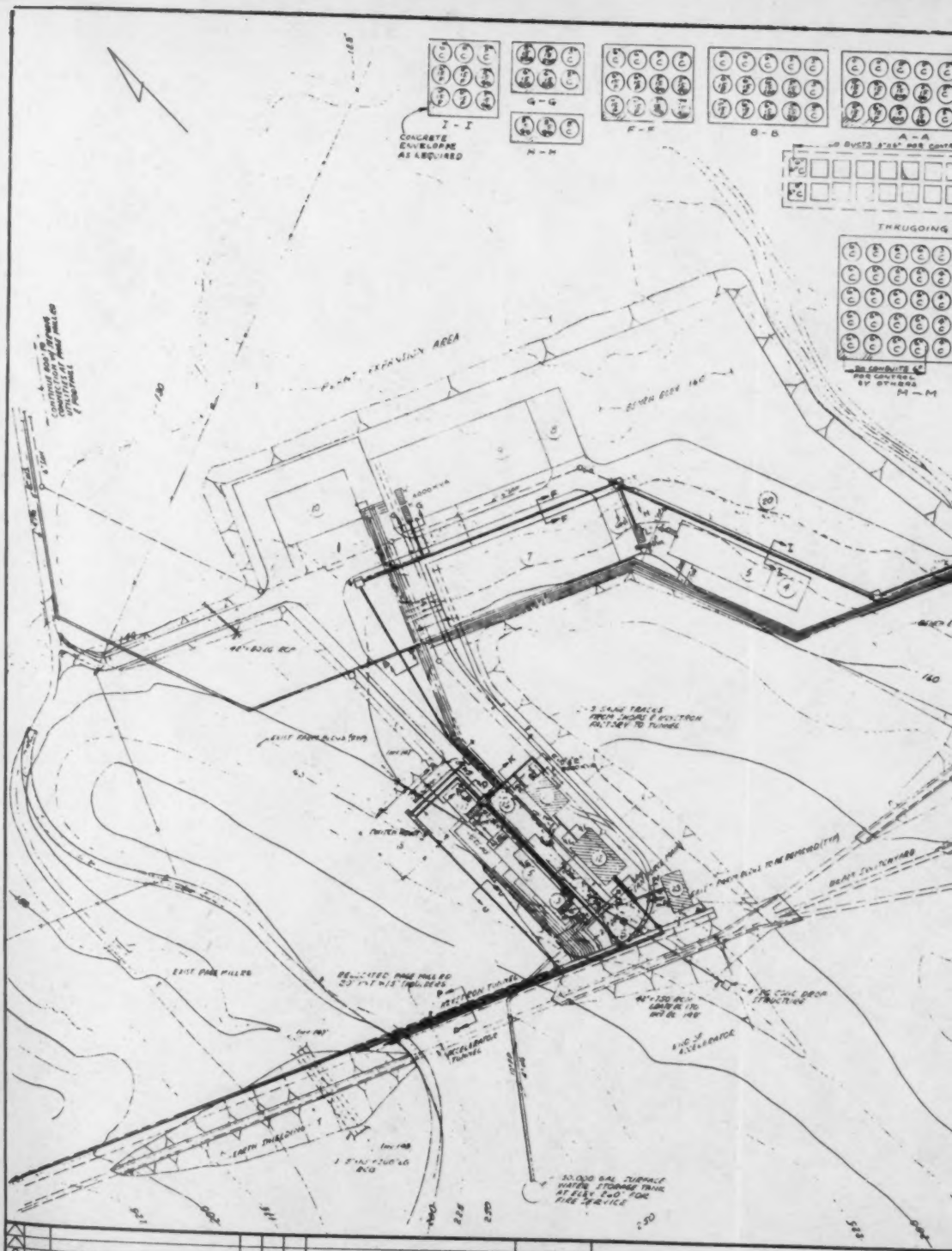
FOR ATOMIC ENERGY COMMISSION

LOCATION STANFORD UNIVERSITY

TWO MILE LINEAR ELECTRON ACCELERATOR

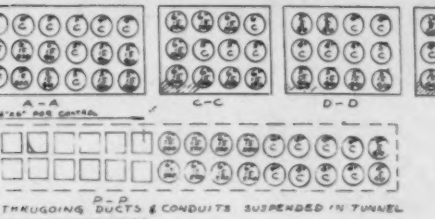
TUNNEL WIRING SCHEME

JOB NO. 5817 DWG. NO. 102-E DESIGNATION R-1



43633 O - 59 (Face p. 526) No. 11

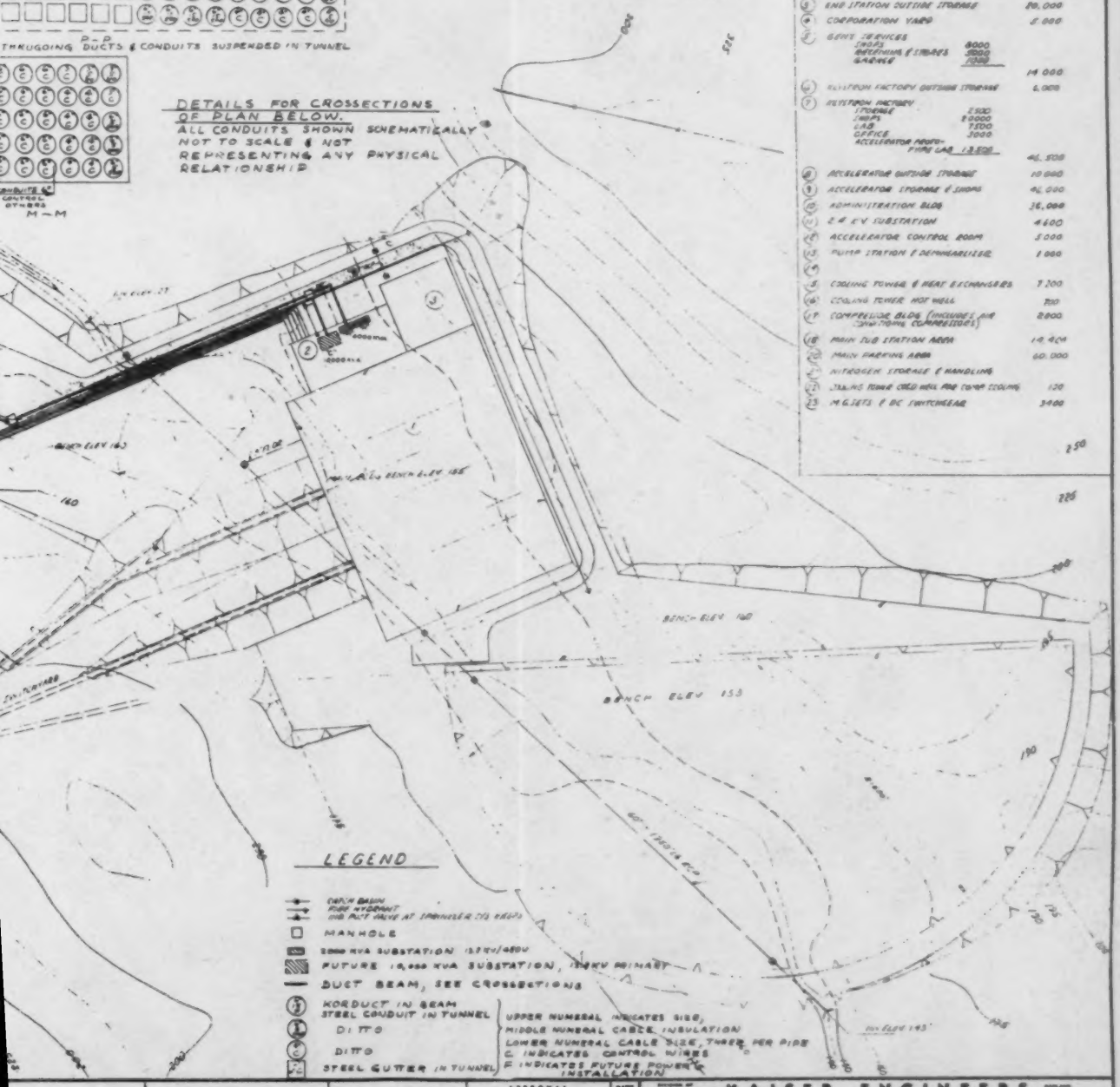
NO.	DATE	REVISION	BY	APP.	APP.	REFERENCE DRAWINGS	NUMBER	NOTES



DETAILS FOR CROSSECTIONS OF PLAN BELOW.
ALL CONDUITS SHOWN SCHEMATICALLY NOT TO SCALE & NOT REPRESENTING ANY PHYSICAL RELATIONSHIP

SCHEDULE OF FACILITIES

(1)	END STATION (MAIN BLDG)		200,000 ø
(2)	END STATION (2 STORY BLDG)		
	OFFICE	12000	
	OBSERVATION	8000	
	STORAGE	3000	
	MACH SHOP	9000	
	RESEARCH LAB		
	PHYSICS	16000	
	ELECTRONICS	4000	
			41,000
(3)	END STATION OUTSIDE STORAGE		20,000
(4)	CORPORATION YARD		5,000
(5)	SCITT SERVICES		
	SHOPS	8000	
	REFRIGERATED STORAGE	3000	
	GARAGE	3000	
			14,000
(6)	KLYSTRON FACTORY OUTSIDE STORAGE		6,000
(7)	KLYSTRON FACTORY		
	STORAGE	5500	
	SHOPS	20000	
	LAB	7500	
	OFFICE	3000	
	ACCELERATOR MODULATOR TYPE LAB	13500	
			46,500
(8)	ACCELERATOR OUTSIDE STORAGE		10,000
(9)	ACCELERATOR STORAGE & SHOPS		46,000
(10)	ADMINISTRATION BLDG		36,000
(11)	2.4 K.V SUBSTATION		4600
(12)	ACCELERATOR CONTROL ROOM		5,000
(13)	PUMP STATION & DEMINERALIZER		1,000
(14)			
(15)	COOLING TOWER & HEAT EXCHANGERS		7,200
(16)	COOLING TOWER HOT WELL		700
(17)	COMPRESSOR BLDG (INCLUDES AIR SWITCHING COMPRESSORS)		2000
(18)	MAIN SUB STATION AREA		14,400
(19)	MAIN PARKING AREA		60,000
(20)	NITROGEN STORAGE & HANDLING		
(21)	COOLING TOWER COLD WELL FOR CORP COOLING		120
(22)	M.G SETS & DC SWITCHGEAR		3400



DESCRIPTION	COST ACCOUNT	APPROVAL	DATE	KAISER ENGINEERS	
				SCALE 1"=100'	DATE
				DRAWN BY M.A Wann	6-20-58
				CHECKED BY Maw	6-20-58
		PROJECT ENGINEER	6/20	APPROVED BY	
		CHIEF ENGINEER		CHIEF PHYSICIST	

FOR ATOMIC ENERGY COMMISSION
LOCATION STANFORD UNIVERSITY

TWO MILE LINEAR ELECTRON ACCELERATOR
POWER LAYOUT OUTSIDE TUNNEL

JOB NO. 5817 | DWG. NO. 103-E | REVISION R-0

WORK COVERED BY THIS DRAWING ENTERED TO COST ACCOUNT ABOVE | CONSTRUCTION APPROVAL

THIS DRAWING IS THE PROPERTY OF KAISER ENGINEERS, DIVISION OF HENRY J. KAISER CONSTRUCTION AND MUST NOT BE USED OR LOANED WITHOUT WRITTEN PERMISSION

Appendix 2

A PROPOSED FEDERAL PROGRAM IN SUPPORT OF HIGH ENERGY ACCELERATOR PHYSICS

BACKGROUND

1. High energy physics is one of the most active fields in contemporary science, and one which has attracted many of the best experimental and theoretical scientists throughout the world. In a sense, it is the most fundamental branch of physics, since its aim is to discover and investigate the elementary particles from which all matter is made. Many of these particles are now known, and the majority of them are unstable; in order to investigate their properties, the experimenter must have means for creating these unstable particles in the laboratory, which is done by converting the kinetic energy of accelerated protons or electrons into the equivalent mass of the new particles. Hence the need for high energy.

The exact energy needed depends on the particle to be produced, as well as the bombarding particle. The better-known class of pions and muons can be made at energies as low as 200 MEV (million electron volts), while the still very mysterious "strange particles" require energies starting at about 1 BEV (billion electron volts) for electron bombardment and about 2 BEV for proton bombardment. To produce some types of strange particles in pairs (in order to get the anti-particles, in analogy to the anti-protons) requires many BEV. The importance of this field in understanding the basic nature of matter and its behavior cannot be overestimated.

2. Experimentation in high energy physics requires expensive devices to accelerate particles to the desired energy, expensive instruments to measure and control particles traveling at speeds approaching the velocity of light and large numbers of scientific and technical personnel. Thus, not only the construction of these high energy physics accelerators, but also their utilization require the expenditure of large sums of money.

3. Immediately after the war, the Federal Government encouraged and supported the construction of high energy accelerators in several universities and national laboratories and, at the completion of these accelerators, funds were provided for the operation of these machines to perform the necessary and desirable experiments. In addition to providing important research results, these accelerators also have provided the training ground for the group of young scientists who are now carrying the responsibility for the future of this field and for many who have since made contributions in other fields.

4. Later requirements were recognized for more and more powerful, and thus more expensive, accelerators. The Federal Government supplied support for these new accelerators, some of which are now operating, others still under construction. Funds for the construction and operation of all new high energy accelerators initiated since 1953 have been provided by the Atomic Energy Commission. Other countries throughout the world - Western Europe and Russia - also have development programs for construction and utilization of particle accelerators for the study of high energy physics.

5. There is now need to review the high energy accelerator program and needs at the Presidential level. This stems from: (a) the extraordinarily high cost of the construction and utilization of high energy accelerators; (b) the fact that all support in this scientific area comes from the Federal Government; (c) the interest of a number of

Government agencies in the science and technology associated with both the construction and the experimental results; and (d) the desire to have an orderly national program taking full account of the activities abroad.

6. A number of groups within the Federal Government have studied this problem. The most detailed examinations have been made by the Advisory Panel on High Energy Accelerators of the Nation Science Foundation.[1/] Other advisory groups which have also been concerned with this general area are the President's Science Advisory Committee, the General Advisory Committee to the Atomic Energy Commission, and the Defense Science Board of the Department of Defense. There is general agreement on the recommendations contained herein among the several groups listed above.

DISCUSSION

7. An adequate approach to high energy physics research requires well rounded coverage of the basic accelerator parameters -- most importantly, the type of accelerated particle (protons and electrons), the energy, the intensity and the beam geometry. Progress in the field will require, in addition to full exploitation of existing accelerators, extensions of certain of these important parameters.

8. Current Situation: The United States has 15 high energy accelerators in operation with energies above 200 MEV (Table I); four of these have energies in excess of 1 BEV and are capable of producing "strange" particles. The highest energy particles now available are 6.2 BEV protons and 1.2 BEV electrons. Four additional accelerators are under construction by the Atomic Energy Commission: a 6 BEV electron synchrotron at Cambridge, Massachusetts. (Harvard-MIT); a 25-30 BEV proton synchrotron at the Brookhaven National Laboratory; a 12.5 BEV proton synchrotron at the Argonne National Laboratory; and a 3 BEV proton synchrotron at Princeton University that will greatly increase the intensity available at that energy. The Argonne and Brookhaven accelerators will be capable of producing all known types of particles.

9. Needed Extensions of Parameters: The most urgent additional needs at present are to extend electron energies, to improve both electron and proton intensities at the higher energies and, where feasible, to improve the beam geometries.

(a) Electrons: The important electron experiments requiring extended parameters are (1) electron-nucleon scattering at higher energies and especially at better beam geometries than the Cambridge accelerator will provide; (2) electron-and photo-production of hyperon pairs. Fortunately, significant extensions of the energy with moderately high intensity and excellent beam geometry are feasible by the linear accelerator method.

1/ The following National Science Foundation Panel reports have been issued:

Report of the NSF Advisory Panel on Ultra High Energy Nuclear Accelerators, MPE Study S-5, May 2, 1954.

Report of the Advisory Panel on High Energy Accelerators to the NSF, October 25, 1956.

Supplement to the Report of the Advisory Panel on High Energy Accelerators to the NSF, NSF 58-29, August 7-8, 1958

(b) Protons: Although there appears to be no immediately compelling requirement for extending the proton energy parameter beyond the 25-30 BEV to be available at Brookhaven National Laboratory (and at CERN, the European Center in Geneva, Switzerland), there is an urgent need for higher proton intensities. Although accelerators now in operation produce strange particles in sufficient numbers to study their production processes, their intensity limitations make very slow and difficult -- and in some cases impossible -- adequate study of the interactions of these particles with other particles. These limitations will be only partly remedied by the accelerators under construction. Interaction studies are indispensible to a determination of the properties of these strange particles and hence to an understanding of their nature and of the role they play in the structure of matter. Hence there is a need for a multi-BEV proton accelerator of much higher intensity than any in the present programs, to produce adequate beams of strange particles, including anti-nucleons. Its energy should be at least 8 BEV.

10. In addition to the need for extending the ultimate energy and intensity limits, the problem of understanding in a quantitative way the detailed processes involved in high energy interactions requires multiple beams of different energies and intensities and floor space to accommodate a large variety of experimental setups. Although present accelerators are properly operated as national assets and are made available to any qualified scientist to the fullest extent practical, the capacities of these instruments are limited both for research and for training even though operated on an around-the-clock basis.

The disruption of the teaching and other academic activities of university scientists makes it difficult for them to conduct experimental research programs on remote accelerators. The need for additional research space, experimental beams and accelerators accessible to university scientists justifies the construction of additional regional or university accelerators, not necessarily of the most advanced design.

11. Needs. The Committee has carefully reviewed the present high energy accelerator program (Table I) in the light of the above factors and finds that the future United States requirements fall into four major categories.

(a) Presently operating accelerators. It is necessary to continue and to expand the support of presently operating accelerators to assure maximum exploitation. This requires continuous updating of facilities, expansion of research space, and the support of major efforts aimed at the augmentation of existing techniques for beam analysis, particle detection and data reduction and analysis.

(b) Accelerators presently under construction. It is necessary that the accelerators now under construction be finished without undue delay and that adequate funds be provided to equip and operate them. It is necessary to give particular attention to providing early support to plans for initial experimental facilities in order that these facilities be efficient, flexible, and available once an accelerator is operating.

It is clear that the Federal Government is committed to provide adequate support to those accelerators which are now in operation or under construction in order to fully exploit the capabilities of the instruments. Thus, regardless of decisions which may be made with respect to the construction of additional

accelerators, high energy accelerator physics can be expected to be costing the Government about $75 - $80 million annually by 1963. This figure must be considered as a base cost upon which any future forward steps must be built. The projected costs shown in Table II and Figure I have been jointly developed by the Atomic Energy Commission, Department of Defense and National Science Foundation and reflect the present degree of diversity of support.

(c) New Construction. There is a clear need for the construction and operation of additional accelerators both to increase the energy and intensity parameters and to increase the U. S. capacity for experimentation in this field.

(1) Extension of energy, intensity, and geometry parameters. There does not now appear to be a clear need for extension of the energy parameter for protons beyond the 30 BEV now in sight at the Brookhaven National Laboratory and CERN. (Paragraph 9(b).) As stated in Paragraph 9 (a) there is an immediate need for a moderately high intensity electron accelerator in the energy region of 10-15 BEV. There is also a need for a high intensity proton accelerator at an energy of 8 BEV or above. Accelerators to meet these needs will cost approximately $15 - $20 million each per year to build and operate. Thus, these two needs can be expected to increase the costs of high energy accelerator physics from $75 - $80 million to about $120 million per year in the course of the next five years.

(2) Increased United States capacity for experimentation. As explained in Paragraph 10, the faculties and students of the nation's universities must have increased access to high energy accelerators. The additional accelerators need not necessarily be unique or extreme in their energy or intensity characteristics in order to fully justify their construction at a site where they may exploit the unique capabilities of a single university or group of institutions. It is our best judgment that by FY 1963 an additional $15 million per year will be required to meet these needs, thus raising the total cost of high energy accelerator physics to between $120 and $135 million per year by 1963.

(d) New Accelerator Concepts. Research and exploratory development of new accelerator concepts must be strongly supported without prejudice to a later determination of need for full-scale construction. In addition, in order to make optimum use of the accelerators, strong support will be required for advancing the techniques of particle detection, data reduction, and data analysis.

12. Policy Considerations and Conclusions.

(a) Need for expanded support. The basic importance of research in the field of high energy physics and its high cost, well beyond private resources, requires the Federal Government to continue to expand its support of this field consistent with valid scientific needs and the availability of qualified research personnel. Consequently, government planning must be based on the need for an increasing level of support from some $59 million in fiscal year 1959 to approximately $135 million in fiscal year 1963, in accordance with the needs outlined in Paragraph 11 (See Fig. 1).

(b) Effect on other areas of basic science. Concern has been expressed that increased financial support for high energy physics may have an adverse effect on the support of other areas of science. In our judgment it should not.

It is not possible to assign relative priorities to various fields of basic science nor should they be placed in competition. Each science, at any given time, faces a set of critical problems that require solutions for continued growth. Sometimes these solutions can be acquired at little cost; sometimes large expenditures of funds are needed. Hence, the cost may not reflect the relative value but rather the need.

Each area must be funded according to these needs. The peculiarly high cost of high energy accelerator physics is due to the size and complexity of the research tools required to attack the fundamental problems of the field. The tools required are proposed by active leaders in the field anxious to devote their talent and energy to developing those tools. Hence, in high energy physics the necessary combination of qualified people with sound ideas for meeting widely recognized scientific needs does exist and the field should be supported.

(c) Priorities. Within the field of high energy accelerator physics, first priority should be given to fullest utilization of existing accelerators including their modification and the continuing provision of new instrumentation. Next priority should be given to adequate facilities for effective use of the accelerators now under construction. Next in importance is the construction of new accelerators required for the exploration of new scientific phenomena beyond the capabilities of existing accelerators and the provision of university facilities.

(d) Guidelines for implementing priorities. The following guidelines should apply in order to assure that the needs outlined in Paragraph 11 are met:

(1) New accelerator construction to extend energy and intensity parameters. Construction should be recommended only when the accelerator is designed to meet a clear research need in physics and after the technical feasibility has been firmly established.

(2) University Accelerators. A university accelerator need not necessarily extend either the energy or the intensity parameter; the accelerator and associated laboratories should be within the administrative and technical capabilities of the university.

(3) Regional Accelerators. Regional accelerators need not necessarily extend either the energy or intensity parameters. The construction of conventional accelerators or accelerators of advanced design and established technical feasibility may be justifiable on the basis of an expressed regional need and a regionable capability.

(e) Diversity of support within the Executive Branch. It is important that the Atomic Energy Commission, the National Science Foundation and the Department of Defense each support research in high energy physics because of their separate responsibilities for the support of basic research, because of the fundamental nature and significance of high energy physics and the corresponding need for each of these agencies to keep

in direct and intimate contact with the scientists in this field and their research. Accordingly, the construction and operation of future high energy accelerators should not be considered the responsibility of any single Federal agency.

The Atomic Energy Commission, Department of Defense and National Science Foundation should each maintain strong interests and contacts in the field of high energy accelerator physics. This can be achieved only through direct financial responsibility and participation in the construction of high energy accelerators. The budgeting for the total cost of construction and operation of a particular accelerator should be the responsibility of a single Federal agency, as sole agent on behalf of all, supplemented by appropriate coordination with the other agencies active in this field.

These large particle accelerators constitute a national asset and should be made available tocompetent scientists elsewhere in this country and abroad to the fullest extent practicable. The support of any given accelerator project by a particular Federal agency should not be construed to prevent or limit the financial support of outside groups using the accelerator by other agencies, public or private.

(f) Coordination. The parallel interest of several Federal agencies in the apport of high energy physics and the impact of this support on national budget planning and programming require a coordinating mechanism to assure effective planning and review at the national level. An interdepartmental council on high energy accelerators should be established to assure coordination of budget and technical planning. The membership of the council should consist of policy level representatives from the Atomic Energy Commission, Department of Defense and National Science Foundation. Technical assistance to the council should be provided by the scientific staff of the three agencies (AEC, DoD and NSF) directly concerned with the administration of high energy physics research programs. The council should be responsible for continuing reformulation of national policies on high energy accelerator physics and the implementation of this policy. This should include the review and coordination of agency programs and plans in the field of high energy accelerator physics and the review of agency proposals for new accelerators.

(g) Review of contracting practices and prefinancing. There should be a review of contracting procedures by the Atomic Energy Commission, Department of Defense and National Science Foundation to assure that such procedures properly support scientific undertakings of this magnitude and character. Present procedures should be revised where necessary so that agencies can provide funds in the contract, for a period of one to three years in advance, for the support of research operations connected with high energy accelerators.

(h) International collaboration. The world-wide scientific significance of research in high energy physics, the extensive, high quality of scientific activity abroad in this field, and the limited number and costliness of high energy accelerators present a unique opportunity for a high degree of international collaboration and cooperation in the planning for and design of future accelerators and in the increased use of facilities. As a first step in the direction of international collaboration looking

toward the development of new high energy accelerators, representative scientific groups from other countries, including the USSR, should be encouraged to meet with us in order to lay plans for cooperative research on new accelerator concepts. The National Academy of Sciences should be requested to advise on the best means for accomplishing this objective.

13. Specific proposals on hand. Consistent with the needs and guidelines outlined in Paragraphs 11 and 12 (d) above, the following comments apply to the three major proposals before the Federal Government:

(a) Stanford University. The Stanford proposal for an electron linear accelerator adequately meets the requirement discussed above (Par. 12 (d)(1)) of a research need for a new electron accelerator and its technical feasibility has been adequately demonstrated. It should be supported fully with the ultimate objective as described in the proposal and with an initial energy of at least 10 BEV. It is desirable that this accelerator project be initiated in fiscal year 1959 in order to avoid an undue delay in high energy research. Because of its dependence on advanced microwave technology, this proposal should be of particular relevance to the interests of the Department of Defense.

(b) Midwestern Universities Research Association (MURA). Although the technical feasibility and research utility of the specific accelerator recently proposed by MURA have not been established, many of the important new accelerator concepts of recent years have come from the ideas and work of the MURA group. Continued progress in these developments is strongly dependent on the continuation and intensification of the MURA program. The group should be supported on a continuing basis with the funds and facilities necessary for its participating intensively in the development, construction and operation of high energy accelerators.

(c) Oak Ridge National Laboratory. The research need for a high energy accelerator at the Oak Ridge National Laboratory should be further explored with the Laboratory and the southern universities concerned. The Oak Ridge group should be supported in continuing design and development activities. The technical feasibility of the accelerator proposed by Oak Ridge has not been established.

RECOMMENDATIONS

14. It is recommended that the Federal Government:

(a) Expand its support of high energy accelerator physics in a manner consistent with valid scientific needs (Par. 11) and the availability of qualified research personnel;

(b) Plan for an increasing level of support for construction and operation of high energy accelerators to a level of approximately $135 million by fiscal year 1963 with the priorities and guidelines outlined in Paragraph 12 (c) and (d);

(c) Note that the increased funds for high energy accelerator physics should be provided without affecting the support of other areas of basic science;

(d) Note that specific needs exist for an electron linear accelerator of at least 10 BEV and a high intensity proton accelerator of at least 8 BEV;

(e) Approve the initiation in fiscal year 1959 of the proposed accelerator project at Stanford University as modified in Paragraph 13 (a),

(f) Note that construction of the Stanford accelerator can be expected to cost approximately $100 million;

(g) Note that initial operating costs of the Stanford accelerator will be approximately $15 million per year once the accelerator comes into operation and that instrumentation and initial experimentation should be undertaken several years in advance of the completion of the accelerator;

(h) Continue to provide adequate support and encouragement to the development group of the Midwestern Universities Research Association;

(i) Encourage the further exploration of the research needs of the Oak Ridge region and the design of accelerators capable of meeting those needs;

(j) Note that the interests of the Federal Government and the scientific community are best served by the direct financing of the projects in this field by the Atomic Energy Commission, Department of Defense and National Science Foundation with the contract authority and budget responsibility for a given project being vested in a single agency;

(k) Approve the establishment of an interagency council at the policy level to assure coordination of budget and technical planning, this council to be assisted by the scientific staff of the agencies concerned;

(l) Approve the provision of contract funds for periods between one and three years for the support of research operations connected with high energy accelerators;

(m) Encourage international collaboration and cooperation in the planning for and design of future machines and the increased use of facilities; and

(n) Request the National Academy of Science to study and advise the Government on the best method for proceeding with international cooperative research on new accelerator concepts, such cooperative activity including the Soviet Union.

TABLE I

U. S. HIGH ENERGY ACCELERATORS PRESENTLY IN OPERATION

MACHINE	PARTICLE	ENERGY	LOCATION
Synchrocyclotron	Proton	0.240 Bev	Univ. of Rochester
Synchrotron	Electron	0.300 Bev	Univ. of California
Synchrotron	Electron	0.300 Bev	General Electric Co.
Synchrotron	Electron	0.300 Bev	Mass. Institute of Tech.
Synchrotron	Electron	0.300 Bev	Purdue University
Betatron	Electron	0.300 Bev	Univ. of Illinois
Synchrocyclotron	Proton	0.400 Bev	Columbia University
Synchrocyclotron	Proton	0.440 Bev	Carnegie Inst. of Tech.
Synchrocyclotron	Proton	0.450 Bev	Univ. of Chicago
Synchrocyclotron	Proton	0.740 Bev	Univ. of California
Linear Accelerator	Electron	0.7 Bev	Stanford University
Synchrotron	Electron	1.2 Bev	Cornell University
Synchrotron	Electron	1.2 Bev	Calif. Inst. of Tech.
Synchrotron	Proton	3.2 Bev	Brookhaven Natl. Lab.
Synchrotron	Proton	6.2 Bev	Univ. of California

U. S. HIGH ENERGY ACCELERATORS PRESENTLY UNDER CONSTRUCTION

MACHINE	PARTICLE	ENERGY	LOCATION	COMPLETION EXPECTED
Synchrotron	Proton	3 Bev	Princeton-Penn (N. J.)	1960
Synchrotron	Proton	12.5 Bev	Argonne Natl. Lab.	1962
Alternating-gradient synchrotron	Proton	25-30 Bev	Brookhaven Natl Lab.	1960
Synchrotron	Electron	6 Bev	Harvard-MIT, Camb.	1960

TABLE II

ANNUAL HIGH ENERGY PHYSICS SUPPORT BY VARIOUS GOVERNMENT AGENCIES BASED ON EXISTING OR AUTHORIZED ACCELERATORS

(In thousands)

FY	AEC		ONR	OSR	NSF	TOTAL
	Operating	Construction				
1946			3,900			3,900
1947		500	4,000			4,500
1948	3,400	600	2,400			6,400
1949	4,800	1,600	2,200			8,600
1950	3,400	7,500	1,600			12,500
1951	5,900	4,100	3,300			13,300
1952	6,300	1,700	1,600			9,600
1953	7,600	2,300	2,400			12,300
1954	7,400	1,900	1,800	270	80	11,400
1955	8,300	1,600	1,500	320	280	12,000
1956	10,200	3,200	1,600	610	220	15,800
1957	16,000	7,000	2,000	930	180	26,100
1958	19,100	12,900	3,300	1,000	210	36,500
* 1959	27,700	26,300	3,300	865	400	58,600
* 1960	36,600	20,500	3,600	950	700	62,400
* 1961	45,900	19,000	4,000	1,150	1,000	71,100
* 1962	53,700	18,800	4,400	1,250	1,500	79,700
* 1963	60,500	9,000	4,800	1,550	2,000	77,900

*Estimated

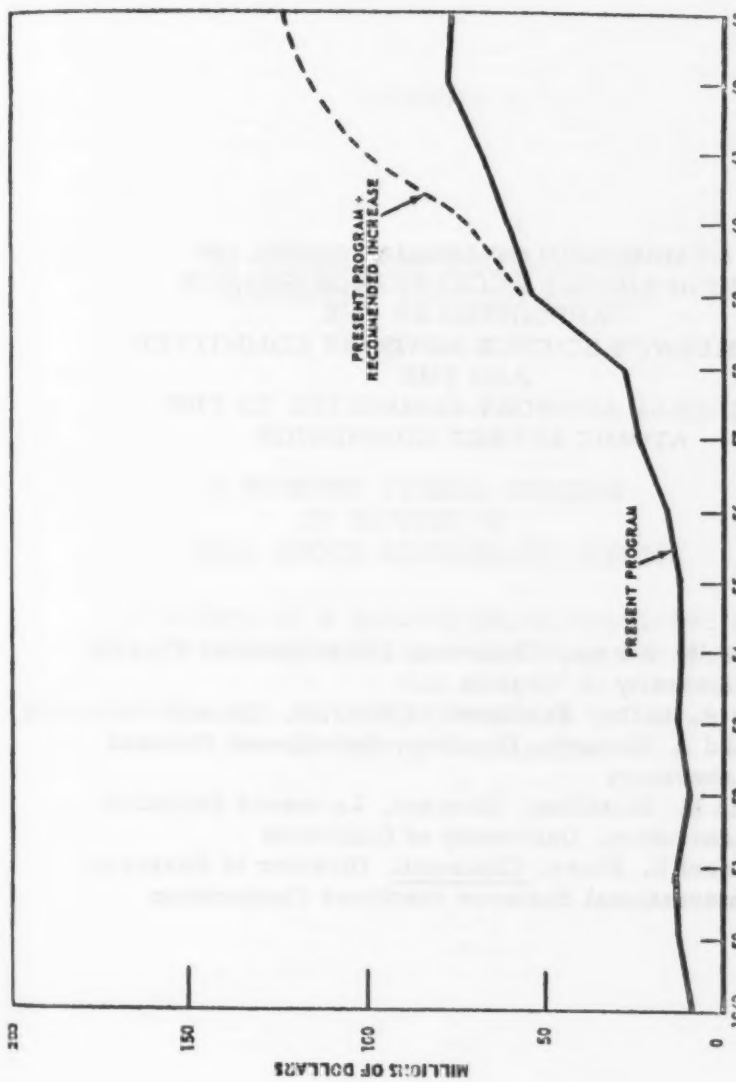


Figure 1 PROPOSED TOTAL EXPENDITURES FOR HIGH ENERGY ACCELERATOR PHYSICS PROGRAM, CONSTRUCTION AND OPERATION (ANNUAL RATE)

MEMBERSHIP OF SPECIAL PANEL ON HIGH ENERGY ACCELERATOR PHYSICS APPOINTED BY THE PRESIDENT'S SCIENCE ADVISORY COMMITTEE AND THE GENERAL ADVISORY COMMITTEE TO THE ATOMIC ENERGY COMMISSION

Dr. Jesse W. Beams, Chairman, Department of Physics, University of Virginia
Dr. Hans A. Bethe, Professor of Physics, Cornell University
Dr. Leland J. Haworth, Director, Brookhaven National Laboratory
Dr. Edwin M. McMillan, Director, Lawrence Radiation Laboratory, University of California
Dr. Emanuel R. Piore, Chairman, Director of Research, International Business Machines Corporation

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Appendix 3

AN EXPLANATORY STATEMENT ON ELEMENTARY PARTICLE PHYSICS

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A PROPOSED FEDERAL PROGRAM IN SUPPORT OF HIGH ENERGY ACCELERATOR PHYSICS

A Report of a special panel appointed by the President's Science Advisory Committee and the General Advisory Committee to the Atomic Energy Commission

Elementary particle physics is the exploration of the subatomic world. It is concerned with phenomena remote from our immediate and familiar surroundings, but applications stemming from this branch of physics have had profound effects upon our technology, our national security, and even our daily living. And yet elementary particle research proceeds, not with any view toward useful application, but by pursuing discovery for its own sake. It is the very heart of modern physics, and the product of many centuries of effort to understand our universe. This statement seeks to convey something of the main ideas of elementary particle physics, its spirit, its methods, its results, and its value to our society.

The realm of the physicist is ever changing. Knowledge of the physical universe increases at an enormous rate, and the physicist -- who explores the rapidly shifting border between the known and the unknown -- continually departs from familiar areas and enters into new and unknown regions. Fifty, even twenty-five years ago the main branches of physics were quite different from present fields of investigation. Radio waves, electronics, the forces that bind molecules, the arrangement of electrons in the atom, the radiation and absorption of light -- indeed, most of the phenomena which so strongly held the attention of physicists half a century ago -- are now part of the subject matter of other disciplines. Just as the mechanical physics of Galileo and of Newton have given rise to the separate professions of mechanical engineering and civil engineering, so these phenomena are now, for the most part, part of the domain of the electrical engineer, the physical chemist, and similar specialists. Even nuclear physics, the main focus of attention of physicists just ten or twenty years ago, has already given birth to the separate fields of nuclear chemistry and nuclear engineering. The frontier of knowledge and with it the chief concern of physics is moving into newer regions.

The exploration of the physical universe has proceeded in two directions, opposite but not unconnected. From the partial understanding

by Newton and his contemporaries of the behavior of the familiar objects of our world, the motions of bodies when forces are exerted upon them, the flow of liquids, or the changes in a gas when we heat or compress it, our knowledge has expanded to encompass phenomena which take place on a scale vastly different from that of our immediate experience, the astronomically large and the submicroscopically small.

Physicists now comprehend not only the structure of stars, the motion of our own and other galaxies, the curvature of space, the possible ways in which our universe has evolved, but also matter on a finer and finer scale: from familiar objects to molecules; then to the atoms of which the molecules are composed; the internal structure of the atom with its electrons orbiting around nuclei; the nucleus itself, made of protons and neutrons and the mesons which bind them together; and lately even something of a picture of the inside of the proton itself, complex and containing yet other particles. We are peeling an onion layer by layer, each layer uncovering in a sense another universe; unexpected, complicated, and -- as we understand more -- strangely beautiful.

Elementary Particles

The basic particles out of whose interactions and combinations our whole universe seems to be formed are called "elementary particles." It is a term whose significance has varied enormously as our view of the physical universe has become more detailed and precise; the changes in its meaning mirror the history of modern physics. In the time of Newton and for almost a centruy thereafter the connection between the structures of different materials was not understood and there were, in this view of our world, as many "elementary particles" as there were kinds of matter: water, salt, oxygen, iron, quartz, etc., an immense number. The uncovering of a finer structure to matter, mainly in the nineteenth centruy, revealed that all matter, with all its different sorts of molecules, was composed of fewer than 100 kinds of atoms; these became the elementary particles of last century's physicists. Shortly before the first world war we had our first look inside the atom. It appeared as a very small core, the nucleus, surrounded by one or more electrons whose configuration determined the chemical properties of the atom. More than two decades ago the tiny nuclei themselves were split open. Observations were difficult,

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fuzzy, approximate, but clearly showed that all nuclei were composed of combinations of protons and neutrons. And so, as we peeled our onion and looked to more infinitesimal distances we saw that our approximately 100 atoms were indeed not truly the elementary particles of our universe, but were themselves made up of a very few kinds: protons, neutrons, electrons. To this list we should perhaps add the light wave. It has had many aliases in our times: electromagnetic radiation, the X-ray, the gamma ray, the quantum, the photon. It has appeared in various guises, identified as different entities according to whether it had great energy, or very little energy, or was acting as a wave (such as sound or ocean waves), or as a particle in the manner of a bullet or a speck of sand. It has been a triumph of modern physics to understand this dualism in the behavior not only of light but of all particles; physicists now realize that what are conventionally labeled as particles have wave properties, and conversely that the light wave is as much an elementary particle as the electron or the proton, or the neutron. But the view that these four particles might be the ultimate elementary particles of our universe has been emphatically destroyed. Remarkable advances in theoretical understanding and experimental technique have revealed that the appearance of our universe is not nearly so simple. Various elementary particles, when looked at with instruments which can resolve extraordinarily fine detail, revealed a substructure involving a host of new and strange particles. Our onion has more skins.

Ways and Means

With our eyes we can distinguish objects whose size is as small as three thousandths of an inch. A microscope is used to see detail on a much finer scale. But the wave nature of light limits the sharpness of detail that can be observed. Theory predicts and experiment confirms that with even the most perfect optical instrument it is not possible to see anything smaller than the wavelength of light. For visible light this is about 0.00001 inch, a thousand times the radius of an atom, a hundred million times as large as a nucleus. And so in the conventional sense we cannot see an atom or a nucleus, nor can we ever hope to do so. The exploration of atomic and nuclear particles demands a different type of vision, different kinds of instruments.

One way to try to see to atomic distances and beyond is to use light of wavelength much shorter than that of normal visible light, X-rays or gamma rays. Such short-wavelength forms of light are

emitted only by sources that can impart a great deal of energy to a single light wave; the higher the energy the shorter the wavelength and the more clearly we can see.

All the sources of very-short-wavelength radiation that are employed by physicists are based on the simple fact that when an electron hits a target it radiates light; the greater the energy of the electron the shorter the wavelength. Thus a beam of electrons is the source of radiation not only from an X-ray tube, but also from betatrons and electron synchrotrons, which use electrons many thousands of times as energetic, and emit radiation whose wavelength is correspondingly many thousands of times shorter.

However, short-wavelength light is not the only tool used to explore down to nuclear dimensions and below, nor is it even the main one. A beam of particles itself can be used, like a beam of light, to probe the atom, the nucleus, and beyond. The astonishing discovery of wave-particle dualism means that particles of matter -- electrons, protons, and all the rest -- behave in many phenomena exactly like light waves. They too have associated with their motion a wavelength which decreases as their energy increases. And, as with light, this wavelength limits the detail that can be examined with a beam of particles. Thus an electron microscope, which uses an electron beam instead of a beam of visible light, resolves more detail because it utilizes electrons whose wavelength is smaller than that of visible light. The resolution increases with the electron energy. Of course a "look" with a beam of electrons gives a picture different from that obtained with visible light. Beams of high-energy protons furnish still another view of our submicroscopic universe. These various aspects are all equally valid descriptions but differ in the precise information which they give. It is figuratively as if we have photographed our landscape with a variety of cameras, one of which films only the houses, another the trees, a third the streets.

The familiar objects around us are unaltered when we turn on a light in order to see them. The molecules and the atoms of a cube of sugar or a glass of water are not appreciably disturbed by visible light. However, if we increase the energy of the light or particle beam in order to decrease its wavelength and see to atomic dimensions, then the energetic light waves or particles seriously shake up the atoms and often break them up into their constituent electrons and nuclei. Beams of short enough wavelength to probe a nucleus also have high enough energy to split the nucleus apart by knocking out the tightly bound protons

and neutrons of which it is made. A detailed observation violently disturbs the system that is observed; this is a quite general consequence of the laws of quantum mechanics, (the description of the behavior of particles on the atomic and subatomic scale). In this way a sufficiently high-energy beam of light (particles) striking a proton or neutron or any other target particle has two associated consequences. It offers a partial view of the target's interior and it frees various new particles which may usually exist only within a struck particle.

Conventional pictures and words are inadequate for the description of these subatomic phenomena; it is not sufficient to think of familiar analogies on a reduced scale. When a piece of wood is chipped from a table we have two new objects, a chipped table and a piece of wood. But occasionally some particles may be "torn" from a proton and still leave the proton intact. In this sense we may consider the new particle to have been "created" in a high energy collision. The "creation" takes energy, for we must still conform to Einstein's familiar relation $E=mc^2$ and supply the energy (E) which appears as the mass (m) of the new particle. An example of particle creation is the production of an elementary particle called the pion or pi-meson. When we probe the proton there is abundant evidence for such mesons in its structure; even their arrangement is in part known. But to "see" the tiny pion inside the proton requires a beam of very short wavelength, and hence high energy. It is a general consequence of the laws of quantum mechanics that the energy of the particles in the beam must be just high enough to create a pion, using the relation $E= m_{pion}c^2$. Thus the same beam which can distinguish the pion inside the proton can liberate (or "produce") pions. Separate measurements can then be made to determine the properties of these free pions. Moreover freshly produced particles like pions can be focussed into secondary beams which are themselves used as probes to obtain a view of the submicroscopic universe different from, and complementary to, that obtained from the primary beams of light-waves, electrons, or protons.

Thus the main tools of the physicist who explores the subatomic uinverse are the beams of high-energy particles which are his light, and the various devices to detect these particles which are his eyes.

High-energy particles exist in cosmic rays, but these are infrequent and uncontrolled. Our understanding of the ultimate structure of matter and energy depends upon the great particle accelerators, which take low-energy electrons and protons and impart to them the enormous energy necessary to "see" to distances which are to the thickness of a sheet of paper as that thickness is to the distance to the moon. The primary beams

of electrons and protons are themselves useful probes, as also are the secondary high-energy beams of light, neutrons, mesons, etc., which they produce.

The various kinds of particle accelerators all work in a similar way. Electrical energy is imparted to an electron or proton by repeatedly kicking the particle, just as the electrons in a wire or a light bulb are kicked when the electrical switch is turned on. The total energy given to the particle is measured in terms of the necessary voltage difference to give an electron this same energy. For a giant accelerator this is some billions of electron volts (abbreviated Bev). The electron or proton may be given a few very hard kicks, as in the linear accelerator, or it may move in a circle and receive an enormous number of precisely timed small kicks, as in the cyclotron and its sophisticated offspring, the Bevatron (6 Bev), and the Cosmotron (3 Bev). The design and construction of these accelerators is an enormous engineering feat which both taxes and expands our technological abilities. The voltage given to a proton by such accelerators equals that from a string of flashlight batteries about a million miles long. Equally sophisticated has been the development of particle detectors, the eyes of the elementary-particle physicist. These range from extra-sensitive photographic film, or specialized counters to detect particles of only a certain speed or charge or mass, through cloud chambers in which particles leave visible droplets in their paths, (similar to the vapor trails behind a jet plane) to similar giant bubble chambers already as large and complicated as cyclotrons. Like the building of accelerators, the design and use of these devices substantially contributes to our technological resources.

Strange and Simple Particles

At present about thirty subatomic particles have been discovered. Their structure is largely unknown, their interactions are only partly explored, their combinations seem to be the basis of all matter. These are now the elementary particles whose number may grow or dwindle as we explore more deeply. Despite our basic ignorance about them, we already know many of their properties and systematic interrelationships. The particle masses have been measured, the electric charges they carry, the kinds of interactions they have with each other. Many are known to be spinning like tiny tops.

Almost half of our elementary particles are a form of matter known as antimatter. Its existence was predicted by the theory of relativity applied to quantum mechanics and has been amply confirmed by experiment. Corresponding to every charged particle and almost every neutral particle there is a twin identical in some properties, opposite in others: the electric charges are opposite, the masses and spins are

identical, their interactions with other elementary particles are closely related. Whenever a particle and its twin come together they annihilate, with total conversion of their mass into rapidly moving lighter particles or even entirely into high-energy light waves. (Again $E = mc^2$ describes the mass-energy balance.) When mixed together, matter and antimatter instantaneously yield more than a thousand times as much energy per pound as an atomic bomb. Although we can create antimatter in collisions of sufficiently high-energy particles, the antiparticles almost immediately collide with neighboring particles and annihilate themselves and these new partners. Antimatter apparently cannot be stored on earth, but the possibility of its existence raises interesting and unanswered questions. Are there regions of our universe normally composed of antimatter just as our local surroundings are entirely normal matter? To what extent would the laws of physics in such regions be identical to our own?

We have come to know some peculiar beasts in our zoo of the elementary particles:

Neutrinos are emitted by radioactive nuclei whenever they emit electrons. Like light waves they have no mass at all and no charge, but, unlike them, almost no interaction with other particles. A beam of neutrinos is unaffected even when going directly through the earth itself. Our sun, whose energy is produced by nuclear reactions, emits an enormous flux of neutrinos. Every second, hundreds of billions of these neutrinos pass through each square inch of our bodies, coming from above during the day, and from below at night, when the sun is shining on the other side of the earth!

Muons are apparently in every way like electrons except that they are 215 times as heavy. A muon is not, however, a stable particle. It lives on the average a millionth of a second, after which it decays into an electron, a neutrino, and an antineutrino.

Pions, or pi-mesons, slightly heavier than muons, have been observed to play a vital part in the structure of protons and neutrons. It is the continuous exchange of pions between neutrons and protons that binds them together into a nucleus, the pions are the main constituent of the nuclear glue. But when free, each of the three kinds of pions -- positively charged, neutral, and negatively charged -- breaks up into other particles. The charged pions decay into muons (themselves unstable) and neutrinos in about a hundred millionth of a second. The neutral pion decays into two high-energy light waves (photons) in less than a millionth of a billionth of a second.

Strange particles are a group of eight newly discovered particles and their antiparticles. They are really no stranger than pions or protons but differ in various properties. They are significantly heavier, so that

only giant Bev-accelerators can produce them and begin to illuminate the role they play in the structure of other elementary particles. Therefore the detailed exploration of their properties has just begun. All the "strange particles" are unstable, and some decay into many different groups of particles. For example, the K meson is a strange particle more than three times as heavy as a pion. It usually decays into a muon and a neutrino, but it can also break up in many other ways. It was the observation of different decay modes for this particle that suggested that an important property known as parity was not conserved -- an idea that has proved fruitful in explaining the emission of electrons from radioactive nuclei. Thus experiments that awaited the construction of giant high-energy accelerators have played a vital role in clearing away misunderstanding in a sixty-year-old branch of low-energy nuclear physics.

The more familiar protons, neutrons, electrons, and light waves (photons) complete the list of the known elementary particles. Besides the neutrino, only these four are stable. Even the neutron can be stable only inside nuclei, the free neutron decays after an average lifetime of 18.5 minutes into a proton, an electron, and an antineutrino. Neutrons and protons are the familiar building blocks of nuclei, which, together with electrons, form the atoms of the hundred different elements.

Because all other particles are unstable, "new" particles created by high-energy beams are always transient. The new particles quickly decay or -- if they are antiparticles -- annihilate with suitable partners. The decay and annihilation products are themselves generally unstable, the chain of degeneration of heavy particles into lighter ones proceeds rapidly. A residual electron or proton or neutron is always found to be a replacement for another such particle, originally present but annihilated by an antiparticle. The ultimate net result of the feeding of electrical energy into giant accelerators is its final dissipation into neutrinos, light (photons), or heat. It is the brief look between these events that, to the physicist, is priceless.

What is to be learned?

We cannot know what will be discovered from deeper probings of the subatomic world. Our only guide is past experience, and here the lesson is evident that nature often turns out to be remarkably different from any expectation. But enough is understood about our physical universe to suggest specific questions whose answers may emerge from further exploration.

The classification of the elementary particles and their interactions is more than a mere catalog. Definite patterns have been recognized which are suggestive of the familiar ordering of the chemical elements in the periodic table. But the pattern of elementary particles is not yet so complete as that of the chemical elements, and there are

numerous possibilities for new particles whose discovery would confirm those regularities which seem to be present.

Perhaps the most remarkable property of the elementary particles is their large number. The feeling of most physicists is that there are far too many for them all to be elementary. It is a situation reminiscent of the time when each of some 100 atoms, the chemical elements, apparently merited the label "elementary." Then a detailed probing within these atoms showed them all to be combinations of protons, neutrons, and electrons, and reduced the number of relevant elementary particles to three. Whether a detailed look at the structrue of our present elementary particles will disclose a similar simplification is one of the profound and critical unanswered questions of the modern physicist. Present accelerators produce beams whose energy is on the borderline of revealing something of the internal structure of these particles, but their energy is still too low to permit such detail to be resolved. Giant accelerators whose energies are some tens or perhaps ultimately hundreds of Bev would be as welcome as powerful glasses to the near-blind.

Despite our ignorance of the answers to the most fundamental questions about the elementary particles, there is one area in which our understanding seems satisfactory. The electron and the light wave and their mutual interaction are a system for which the fusion of quantum mechanics, relativity, and the theory of electric and magnetic fields, into the new theory of quantum electrodynamics, although certainly incomplete, has produced answers in fantastically good agreement with experiment. Therefore it has been the model for attempts to build theories to describe the other elementary particles and their interactions. It remains to be seen whether this single successful theory remains valid when higher energy beams of electrons and light become available.

Our various laws of physics generally do not remain unaltered as we seek to apply them to ever more diverse phenomena. We see them rather as approximations accurate and sufficient only in limited domains. To preserve the law of conservation of energy, first heat and then matter had to be considered forms of energy. The epoch-making Newtonian laws of motion are now seen to be valid only for velocities much smaller than those of light. For the description of atomic particles conventional mechanics is superseded by quantum mechanics. Physicists wonder whether relativity and quantum mechanics will continue to be correct descriptions of nature as we explore to smaller and smaller distances. Do signals always propagate at speeds smaller than that of light no matter how small the interval? Does the relation between energy and wavelength hold for arbitrarily small wavelengths? Even if we learn that our present laws remain valid in this new region, the knowledge that this is true would be of enormous significance.

It may be that our very ideas of space and time may not be adequate for continually deeper exploration of the subatomic world. Is there perhaps a smallest distance inherent in space itself? Can ordinary Euclidean geometry continue to be applicable to such incredibly small lengths? We already know that it is not applicable to enormously large ones. Perhaps the answers to such questions may illuminate the long-sought connection between inner space and outer space, the submicroscopic and the astronomical universes.

* * * *

Pure research, stimulated by curiosity and the satisfaction of accomplishment, has given us knowledge and understanding of many of the phenomena of our world. The rapid exploitation of such discoveries, especially in this century, has resulted in our present amazing technology. These tangible returns from pure research have been gigantic. From the brilliant investigations of nineteenth-century physicists on the nature of electric and magnetic fields have developed electric power, electronics, radio, television. Examples from the past are countless. Even in recent decades we have witnessed enormous application of discoveries merely incidental to research in elementary-particle-physics: isotopes, nuclear fission and power, medical therapy with high-energy beams, a step toward controlled thermonuclear power -- a list that continues to grow rapidly.

The practical results that must derive from continued exploration with larger accelerators cannot be guessed. If the past is a guide they will be numerous and fantastic. The one thing that we have learned to expect from nature is to be surprised.

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Appendix 4

Comments on the Proposed Stanford Accelerator and the National Research Program in High-Energy Physics

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I. INTRODUCTION

Some excellent background material on this subject is presented in the report of the panel appointed by the President's advisory committee. The following is aimed at fairly specific questions which have arisen, or may arise, in connection with the authorization for the Stanford machine. Section II contains a summary of the aims of high-energy physics, together with general descriptions of the types of equipment required to implement these aims. Section III is a discussion of the validity of the Stanford research aims. Section IV is a simple statement of confidence in the feasibility and the reliability of the cost estimates for the machine. Section V attempts to ask and answer some questions as to how the Stanford machine will fit into the future high-energy program of the country. Section VI is an attempt to tabulate some of the related accelerators of the world.

II. AIMS AND METHODS OF HIGH-ENERGY PHYSICS

Modern high-energy research began its evolution about twelve years ago out of cosmic ray research. The cosmic ray work had made extensive studies of the very energetic particles which constantly impinge on the earth's atmosphere from outer space. This work had progressed in 1947 to the point that the impinging particles were pretty clearly known to be largely protons of an energy then unachievable in terrestrial laboratories. It had just been established that these protons continually generate, by collision in the extreme upper atmosphere, previously unobserved particles, the pi-mesons. The pi-mesons in turn decay to mu-mesons, which in some cases reach the earth's surface, and in other cases decay, producing tremendous bursts of ionization in the atmosphere by a mechanism which had long been clear.

This most interesting process had resisted complete elucidation because one essential step occurs at very high altitudes, so that observation is difficult. The pi-meson, which had remained hidden for so many years, was in fact the long awaited key to a real understanding of the forces which bind nuclei together. Clearly an extensive study of the pi-meson by more convenient and precise methods was called for. At this point, the 184-inch cyclotron at Berkeley (which had been built for other reasons) became the first artificial producer of pi-mesons, and it was at this point that modern high-energy physics began.

With such successes accomplished, physicists had little trouble obtaining support for larger machines of the Berkeley type. These machines

have completely justified the hopes of their builders by vastly increasing our knowledge and understanding of nuclear phenomena. The time scale of this development is impressive, a very large fraction of the pi-meson work having been done in the past ten years.

The great success of the Berkeley work quickly led, not only to more machines of that type, but also to the confidence that larger machines of a different type should be capable of valuable results. The Brookhaven Cosmotron and Berkeley Bevatron were thus conceived, supported and built without a really detailed idea of what they were to do. Their work turned out to be the elucidation of the properties and role of some new particles which had again first appeared in cosmic ray observations as early as 1947. As with the pi-mesons, careful study and real understanding had to await a machine to produce them with useable intensity under controlled conditions. Because of the larger masses of the particles involved (the so-called strange particles), the cyclotron which had served for the pi-meson was inadequate. The first definitive work on the strange particles was the fruit of the Cosmotron (3 Bev) research program. The Bevatron (6 Bev), with its considerably higher energy beam, has allowed many strange particle studies for which the Cosmotron energy is inadequate. In addition, the anti-proton, whose production was the original justification for the Bevatron energy choice, has in fact been produced, as a nice demonstration that physicists can occasionally "call their shots".

The large Russian machine (10 Bev) is on the direct line of evolution of the Bevatron and should be capable of extremely valuable work. Its

performance has only recently become acceptable and it is still too early to guess what its essential contribution will be.

This general family of machines, the proton accelerators, is still developing and will shortly give rise to the large Brookhaven and CERN proton accelerators (25 - 30 Bev). The motivation with these machines is in part to supply enough energy to be able to produce new particles and study their properties. In part they are aimed for efficient study of particles already discovered, in an attempt to obtain real understanding of their role in nature.

Although a design study has been made for a very large (50 Bev) Russian proton machine, and larger ones have also been seriously studied, the urge for higher energies to uncover new particles seems to be less strong than it once was. First, no particles have been discovered that were not first seen in cosmic ray work. The apparent exception is the antiproton, which has the honor of being the best predicted particle in the catalogue. Second, a very effective classification scheme for the particles now exists, which leaves less room for new particles. Third, as the energy of impact is increased, the target tends increasingly not to "stand still" for the collision. The result is that in increase from 25 to 50 Bev by no means adds 25 Bev to the mass of the particle which can be created, but rather more like 3 Bev. The search for high mass particles accordingly becomes expensive and technically difficult.

The Princeton and Argonne accelerators are examples of a new trend, namely an emphasis on convenience and precision in the study of particles

whose existence and general properties have been previously demonstrated (or at any rate rendered plausible). This trend is apparent in the MURA and Oak Ridge concepts, which emphasize beam intensity much more heavily.

At the same time that the proton accelerator family was developing, an analogous electron family was evolving. The motivation was at first vague, but successful circular electron accelerators (betatrons and synchrotrons) were on hand to aid the early development of the pi-meson work (Illinois, Cornell, M.I.T., and Berkeley). The production of pi-mesons by x-ray beams from these machines turned out to be crucial, not as a source of pi-mesons, but for the understanding of the particles.

This pattern has persisted and fully justified the enterprise of the designers, who were subject to much criticism from the builders of proton machines. The point at issue was the relative weakness of the interaction between nuclear particles and x-rays. As it turned out, the interaction was at least strong enough to allow careful measurements, and it was simple enough to allow reliable interpretation of the results.

Another research pattern was widely suggested, but finally found real fruition only at Stanford. This was the use of the electrons as probes for the study of the detailed structure of relatively familiar objects such as nuclei, protons, neutrons, and electrons. In this application, the electron beam performs the same function as the beam of light in a microscope, and the experimental arrangement replaces the lenses of the elementary instrument. The net result can be a precise picture of the actual arrangement of electric charge in a nucleus, or an elementary particle, a truly amazing result by standards of ten years ago.

The previously mentioned circular electron machines have sufficient energy to yield interesting information on structure, but in fact they have not been so applied. The reason is simple and bears strongly on the validity of the Stanford proposal. The electron beam in a circular machine is difficult to extract for external use, so that only the less useful (for this purpose) x-ray beam is in practice available.

Another difficulty of the circular electron machine is directly caused by the necessary bending of the electron path. At the speeds attained (very close to that of light), the electrons lose energy very rapidly by emission of light with the result that circular electron machines become very difficult above about 5 Bev, and probably prohibitively so above 10 Bev.

III. VALIDITY OF STANFORD AIMS

The linear accelerator does not bend the electron path, so that the radiation is absent. Further, the beam emerges without special provision. For these two reasons, the linear accelerator appears to be ideal for the investigation of structure. In this connection, it is important to remember that the size of the smallest detail that can be revealed by an electron beam decreases rapidly as the energy of the beam increases. Thus the extensive work of Hofstadter and his colleagues has been performed with the present Stanford linear accelerator at energies up to about 1/2 Bev. These studies have revealed a reasonable amount of detail on the structure of nuclei, with revolutionary effects on our theoretical conceptions. Some structure has been seen for the proton and neutron, with even more far-reaching results. The end of this work is very definitely not yet in sight, although the present machine is incapable of much greater detail.

An equally intense and well-controlled beam at twenty times the energy 10 Bev at which six times the detail can be seen as at $\frac{1}{2}$ Bev, for protons and neutrons therefore seems certain to first raise, and then answer greater detail, which is of great value in checking and inventing more complete theories of the nucleus and its constituents, there is a more fundamental question of the very meaning of distance in small scale phenomena. It may well be that the presently well-established theory which accurately describes and largely explains a wealth of complex phenomena involving electrically charged particles and light waves, may

prove to be inadequate for these high-energy collisions. There is already some evidence for this interesting state of affairs, and a clear cut demonstration of the breakdown would have far-reaching consequences for our conceptions of small scale physics.

It has further been amply demonstrated that a 10 Bev electron beam will serve to generate ample supplies of all the known or anticipated strange particles, so that completion of Phase I (10 - 15 Bev) will allow support of as varied and productive a research program as the Argonne machine, for example. Phase I will not allow production of any possible presently unknown particles which are beyond reach of the large Brookhaven or CERN proton accelerators. Phase II (~45 Bev) very definitely would allow exploration for further particles. Further, if the large proton machines should uncover new particles, then the high intensity of Stanford Phase II might be vital in consolidating the new field.

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IV. TECHNICAL PROBLEMS OF THE STANFORD ACCELERATOR

The writer has no detailed competence in this accelerator type, but certain comments are quite easy to make. On the favorable side, considering the high claimed performance, the proposal is remarkably free of technical difficulties and cost uncertainties. This is the result of the extensive experience with the present Stanford machine, which makes possible a simple extrapolation to the larger machine. The independent cost estimate by William M. Brobeck and Associates is much more detailed than any ever before prepared prior to construction authorization. It fails to reveal any such gross optimism on the part of the Stanford group as it has become customary to expect. There seems to be no reasonable basis to doubt that the requested funds will allow completion of the planned machine, with highly successful operation. To summarize, the Stanford proposal is very much more free of technical problems than has been the case for any previous accelerator.

V. RELATION TO PRESENT AND FUTURE MACHINES

It has been indicated that the Stanford machine will represent a very large gain for one very important branch of high-energy physics. There are, however, other machines which can contribute in this one branch, and other branches which must be considered. Does the Stanford machine seriously overbalance the electron part of the country's high-energy program? First, it should be emphasized that the electron machines have thus far been under-supported, in view of the proven validity of the Stanford research program. Second, as has been stated, the Stanford proposal is the only known way to achieve an intense, well-controlled electron beam at energies in the range above 10 Bev. Without a development program of uncertain magnitude and success, it is the only way to achieve such a beam below 10 Bev.

For these reasons, the aims of the Cambridge Electron Accelerator and the Stanford proposal partially overlap only where the x-ray beam is to be used. The CEA will probably not be used effectively for structure studies, and it therefore does not seem wise to defer initiation of construction on the Stanford machine until some essentially irrelevant studies have been completed on CEA. The energy gap of at least 4 Bev between CEA and Stanford Phase I does not in itself appear crucial at this time.

On the negative side, only part of the work of large proton machines can be effectively handled by the Stanford machine. The proton machines are relatively useless for the study of structure, but they are highly competitive for the production of strange particles. It is probably

fair to say that a circular proton machine with performance equivalent to the Stanford Phase I could be built for one-third the cost of the Stanford machine. The relative importance of the structure determination work and the strange particle studies has changed, and presumably will change, with increasing information. It therefore seems unwise to allow the Stanford machine to dominate the high-energy research picture of the future. It may be noted at this point that two factors conspire to reduce the effectiveness of the linear electron accelerator for simple production of strange particles. First, for a beam with a given current of particles, electrons will produce many times fewer interesting particles than protons. Second, the linear accelerator produces its particles in very short, intense bursts, which will cause counters to fail at a current level which could be handled in longer pulses. This is the so-called "duty-factor" difficulty.

One other point, which is of obvious importance lies in the uniqueness of the Stanford facility. Although the writer sees nothing incongruous in the proposed operation by a university, still it is clear that very rigid precautions must be used to steer a safe course between two opposite dangers. The first is that access to the laboratory facilities should be so rigidly controlled as to discourage participation by competent workers in other parts of the country. The other danger is that no effective control is exercised over such access, so that poorly conceived experiments are able to seriously interfere with the really important programs.

Present and Planned Accelerators of the World

It may help in putting the Stanford proposal in its proper relation to the rest of high energy physics if we tabulate those accelerators most closely related to it by virtue of energy or particle type. The status of the machine will be indicated, and an attempt will be made to describe the existing or probable future research program.

The unit of beam energy which has been used throughout is the Bev (Billion Electron Volts). This unit, commonly used in the field of high energy research, is relevant because a proton with this energy is moving with a speed close to that of light. Such high speeds are essential to produce the phenomena of interest.

In the attached tabulation an arbitrary unit is used to express the relative beam intensity of the beams generated by the various accelerators. Beam intensity is the number of particles produced per unit of time.

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Very High Energy Proton Accelerators of the U.S.

Very High Energy Proton Accelerators of Other Countries

Electron Accelerators of U.S. and Other Countries

MULTI-BEV PROTON ACCELERATORS (U.S.)
(THESE ARE ALL CIRCULAR MACHINES)

MACHINE (NAME & LOCATION)	MAXIMUM BEAM ENERGY (BEV)	STATUS	INTENSITY (ARBITRARY SCALE)	PRINCIPAL WORK IN PROGRESS OR PLANNED
COSMOTRON (Brookhaven National Laboratory)	3.0	Operating (1952)	20	Studies of strange particles.
BEVATRON (Lawrence Radiation Lab., Berkeley)	6.2	Operating (1954)	4	Studies of strange particles and anti-protons.
AGS (Brookhaven National Laboratory)	30-33	Construction Completion 1960	0.5	Studies of strange particles and anti-protons. Search for anticipated anti-hyperons.
ZGS (Argonne National Laboratory)	12.5	Construction Completion 1962	250	Studies of strange particles, anti-protons, and anti-hyperons.
PRINCETON-PENN. (Princeton)	3.0	Construction Completion 1960	3000	Studies of strange particles.
MURA (Madison)	15.0	Design Study	120,000	Studies of strange particles, anti-protons, and anti-hyperons. Possible use of colliding beams to search for unexpected new particles.
OAK RIDGE (Oak Ridge National Laboratory)	12.0	Design Study	120,000	Studies of strange particles, anti-protons, and anti-hyperons. Possible use of injector for detailed studies of pions and muons.

MULTI-BEV PROTON ACCELERATORS (FOREIGN)
(THESE ARE ALL CIRCULAR MACHINES)

MULTI-BEV PROTON ACCELERATORS (FOREIGN)
(THESE ARE ALL CIRCULAR MACHINES)

MACHINE AND LOCATION	MAXIMUM BEAM ENERGY (BEV)	STATUS	INTENSITY (ARBITRARY SCALE)	PRINCIPAL WORK IN PROGRESS OR PLANNED
DUBNA (USSR)	10.0	Operating 1958?	0.4	Studies of strange particles, anti-protons, and anti-hyperons.
MOSCOW (USSR)	7.0	Construction Completion 1960	2.0	Studies of strange particles and anti-protons, prototype studies for 50 Bev machine.
LENINGRAD (USSR)	50.0	Design Construction Begun 1957?	0.6	Studies of strange particles, anti-protons and anti-hyperons. Search for new particles.
GENEVA (CERN)	28.0	Construction Completion 1960	1.7	Studies of strange particles, anti-protons, and anti-hyperons. Search for new particles.
HARWELL (U.K.)	7.0	Construction Completion 1961	500	Studies of strange particles and anti-protons.
SACLAY (France)	3.0	Operating 1958	0.3	Studies of strange particles.

MULTI-BEV CIRCULAR ELECTRON ACCELERATORS*
(U.S. AND FOREIGN)

MACHINE (NAME AND LOCATION)	MAXIMUM BEAM ENERGY (BEV)	STATUS	INTENSITY** (ARBITRARY SCALE)	PRINCIPAL WORK IN PROGRESS OR PLANNED
CEA (Cambridge, U.S.)	6.0	Construction Completion 1960	200 (Converted to X-rays)	X-ray production of strange particles and anti-protons. Studies of these particles. Possible structure studies by X-ray scattering.
HAMBURG (West Germany)	7.0	Design Construction?	200 (Converted to X-rays)	Similar to above.

BEV AND MULTI-BEV LINEAR PROTON ACCELERATORS
(U.S. AND FOREIGN)

ORSAY (France)	1.0	Construction Completion 1960	200 Electrons or X-rays	Production and study of strange particles by X-ray and electron beam. Structure studies by electron beam.
KHARKOV (USSR)	1.0-4.0?	Construction Completion?	?	Same as preceding.
MARK III (Stanford, U.S.)	0.7	Operating 1952	200 Electrons or X-rays	Production and study of pions and muons by X-ray and electron beam. Structure studies by electron beam.
PROPOSED STANFORD ACCELERATOR	10.0-15.0 (45.0?)	Design	6000 Electrons or X-rays	Production and study of strange particles and anti-hyperons by X-ray and electron beam. Structure studies by electron beam extended to much finer detail. Search for new particle with Phase II (45 Bev).

* A large number of U.S. and foreign circular machines at roughly 1 Bev are operating or under construction. These are omitted as being not sufficiently relevant.
** The intensity scale is so chosen as to compare directly with the proton machines for production of strange particles.

Appendix 5

TECHNICAL REPORTS AND JOURNAL ARTICLES

ON

PARTICLE PHYSICS

ACCELERATOR DEVELOPMENT

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W. W. Hansen Laboratories of Physics
Stanford University
Stanford, California

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Appendix 6

W. W. HANSEN LABORATORIES OF PHYSICS
STANFORD UNIVERSITY
STANFORD, CALIFORNIA

MICROWAVE LABORATORY
HIGH ENERGY PHYSICS LABORATORY

DAvenport 3-2441

July 22, 1959

The Honorable Melvin Price, Chairman
Subcommittee on Research and Development
Joint Committee on Atomic Energy
Congress of the United States
Washington D.C.

Dear Mr. Price:

Enclosed with this letter you will find material which I was asked to supply at the recent hearings on the geology of the region where the tunnels for the proposed linear accelerator are to be located.

The material is presented to you in a form of report which contains a number of items which are important by way of background information. This report was prepared by the staff geologists of the Hansen Laboratories of this University, and contains their conclusions concerning the feasibility of building tunnels on this site.

In addition to the conclusions reached by our own staff, our opinions are supported by a number of other individuals expert in the field. These are contained in Appendix E of the report, to which we should like to invite your careful attention.

Not included with this report is the opinion presented to us on a number of occasions during the last two years by Stanford Professor Benjamin M. Page, Head of the Department of Geology. In his verbal discussions with us he has presented an unqualified opinion that there is no undue hazard in the construction of the tunnels at this site; his opinion was based upon his personal study of the site and upon the geologic information assembled for him by his assistants. This specific information is included in Appendix D of the enclosed report. We are not able to present to you Professor Page's personal support of the project because of his absence from Stanford on a sabbatical leave. If you feel it important, a written statement from Professor Page can be obtained by communicating with him in Italy.

Several other individuals have been consulted during the last several months to check the validity of our conclusions. We can report to you that in no case has evidence been produced which would contradict the conclusions reached by the five groups of people referred to above.

Please do not hesitate to ask us further questions.

Sincerely yours,

E. L. Ginzton

E. L. Ginzton, Director
Microwave Laboratory

cc: Mr. J. T. Ramey
Dr. J. Williams

SITE FEASIBILITY OF STANFORD'S PROPOSED 2-MILE LINEAR ELECTRON ACCELERATOR

By

Frank W. Atchley

Robert O. Dobbs

Stanford University
July 1959

July 20, 1959

Professor E. L. Ginzton, Director
Microwave Laboratory
Stanford University
Stanford, California

Dear Dr. Ginzton:

Presented herewith is our report on the site feasibility of the proposed linear accelerator based on information acquired to date, including documentation where possible.

It is our considered opinion that with respect to geographic location, topography, relative construction costs, and natural hazards, the proposed site is a feasible location for the planned accelerator.

Very truly yours,

Frank W. Atchley

Frank W. Atchley

Robert O. Dobbs

Robert O. Dobbs
RESEARCH ASSOCIATES
(Geologists)

INTRODUCTION

The purpose of this report is to assemble the information acquired to date concerning the feasibility of the Stanford site for the proposed 2-mile linear electron accelerator. The report is based on extensive review of the literature, photo-geologic interpretation, previous field mapping, discussion with eminent authorities in the fields of Seismology and Earthquake Engineering, and personal experience.

The evidence assembled to date clearly indicates that the proposed site is a feasible location for the construction of the linear accelerator. However, further detailed work, including mapping, soil and rock testing, subsurface drilling, and bulldozer exploration will be needed in order to establish the specific project alignment and foundation conditions for engineering design. In addition, in order to establish engineering safety factors that are commensurate with reasonable risk, eminent authorities in the fields of Seismology, such as Dr. Perry Byerly, University of California, and of Earthquake Engineering, such as Dr. George W. Housner, California Institute of Technology, will be consulted.

SUMMARY AND CONCLUSIONS

The study of site feasibility for a project such as the proposed linear accelerator requires careful consideration of project objectives, geographic location, topographic situation, and specific geologic conditions with respect to possible prohibitive construction costs, and hazards which could impair the usefulness of the project. Evaluation of these factors leads to the following conclusions:

1. The proposed site provides a very favorable geographic location close to related research activities at Stanford University and available supply, power, and scientific manpower sources.
2. The project requirements of tunnel length, tunnel cover, desirable side portal, adequate research working area, and sound stable foundations are all provided by the proposed site. The project area is on available Stanford land.
3. The geology of the site does not offer construction hazards or tunneling conditions which would significantly alter conventional design practices or tunneling methods, which factors together determine construction costs. The site has been examined by the Utah Construction Company, Bechtel Corporation, and Kaiser Engineers, and independently they reached the conclusion that the site was a feasible location for the proposed project.
4. Earthquakes in the San Francisco Bay Area are a recognized hazard. However, overwhelming empirical evidence proves that, although an area is hazardous, a minimum of danger exists to properly designed structures located on or in bedrock foundations. In the San Francisco Region there are mountain tunnels, a submarine tunnel, numerous skyscrapers, and the Bay Bridges, all of which

are earthquake-proof structures. The problem is merely a matter of engineering design and selection of best possible foundations.

5. Earthquake damage to tunnels rarely occurs. When damage does occur, it is only to improperly designed, poorly supported tunnels, or is in areas of incompetent rock in steep mountainous terrain. Even then damage occurs only when the tunnel is crossed by an active fault or is located in the epicentral area of the earthquake. The proposed tunnel will be specifically designed to resist earthquakes and will be driven in relatively competent rock in an area of gentle topography. No known active faults cross the proposed tunnel site, which is located 4 miles from the nearest zone of known epicenters along the San Andreas Fault. Therefore, we believe that there is a negligible risk involved in building the linear accelerator at the proposed site.

SITE REQUIREMENTS

The structures required to house the proposed linear accelerator are described in Stanford's initial proposal of April, 1957. However, at that time the desired site requirements of the proposed structures had not been defined, particularly the requirements which would insure optimum operating conditions. These requirements are summarized below. It may be said that the requirements demand careful geological evaluation, and dictate that the site have particular topography.

1. The principal structures will be two parallel level tunnels, 10 and 24 feet in diameter and 10,000 feet long. When completed, the tunnels will be in 24-hour continuous use, with personnel in the larger tunnel at all times. The continuous use, presence of personnel, and type of equipment demand particularly safe tunnels. There must be suitable tunnel access for personnel, equipment, ventilation, etc., and a centrally located side portal if at all possible. There must be adequate cover over the tunnel to insure safe radiation shielding.
2. The accelerator target will be housed in a radiation-proof structure which measures 400 feet by 500 feet, with 8-10 foot thick walls approximately 100 feet high. This structure should have particularly sound, rigid bedrock foundations, if at all possible.[1]
3. Pinpoint target accuracy with deviations of one inch per year or five inches over a period of years is desired for operating convenience. This requirement does not raise construction problems, but does dictate stable foundations for the target building and the accelerator tunnel. It should be emphasized, however,

[1] Revised paragraph 2, appears on p. 583

that the degree of stability stated above is desirable but not critical and that deviation up to five feet can be tolerated.

4. There must be adequate working space in the target area for present and future experimental purposes. Ideally, the target area should be enclosed in an amphitheater valley, with steep natural hillsides for horizontal radiation shielding.

2. The proposed research requires both a main test building and an exterior target area. The test building will measure 400' x 500', by 100' high, with floor foundation suitable for supporting heavy equipment. The contemplated building will consist of a steel framework of sufficient strength to support heavy overhead crane loads, and will be covered by asbestos siding or similar material. The point loading conditions demand rigid bedrock foundation if at all possible. Radiation shielding within the building will be provided around individual targets, or more generally if and when needed. The exterior target areas need only be reasonably level with sound soil or rock foundation.

SITE FEASIBILITY FACTORS

The proposed project site is on available Stanford land which has been reserved for this purpose. The site is located only two miles south of related research activity at Stanford University, and geographically located where power and supplies, as well as scientific manpower to plan, direct, and staff the project are available.

The topography of the site affords a suitable location for level, 10,000-foot tunnels with open portals on either end and a centrally located side portal. The target area, with nominal excavation, will provide adequate working space for all future needs and the excavation will insure sound bedrock foundation for the target building. The excavation also provides hillside radiation shielding. In short, from the point of view of location and topography, the proposed site appears ideally suited for the project. There yet remains the question of geological feasibility of the site.

Investigation of geological feasibility of tunnel sites may be resolved to specific questions concerning possible prohibitive construction costs, and hazards that could impair the usefulness of the tunnel following its completion. Satisfactory answers require careful consideration of regional and local geology, and knowledge of project objectives, engineering design limitations, and construction costs.

The relative importance of the geological factors which affect the ultimate construction costs, including corrective and preventive measures for hazards that are known to be present, can vary greatly. For example, there is general agreement that with sufficient justification a safe usable tunnel can be designed to counteract practically any unfavorable geological

situation, from running quicksand and underground rivers to solid granite. The problem lies in detecting and defining the hazards that are involved and the working conditions which will be encountered during construction.

Construction Costs

Tunnel construction costs may vary tremendously, depending on specific geologic conditions. It is necessary to assess in dollars and cents the significance of rock character and geologic structure with respect to tunnel diameter, excavation difficulties, and roof support requirements. It is necessary to appraise the portal areas with regard to access, working area, muck disposal, storage, and availability of power. Necessary contingencies must be included for unexpected excavation and support difficulties and for extra pumping and ventilation in case groundwater, natural gas, or high temperatures are encountered.

In the present case, the project area has been examined by three recognized engineering construction firms, the Utah Construction Company, Bechtel Corporation, and Kaiser Engineers. For comparative purposes these firms considered different project alignments in the same general area and, in each case, reached the independent conclusion that the site was a feasible location for the proposed project. The three firms were requested to amplify and explain their respective conclusions for permanent record. Their summary conclusions are bound as Appendix E.

Tunnel Hazards

The major tunnel hazards, other than those which affect the tunnel design and construction costs, are limited to phenomena which could render

the tunnel unusable after its completion.

These hazards are summarized below. The seriousness of any one is a question of probability of occurrence, monetary value of interrupted operation, and repair costs:

1. Tunnel collapse or failure due to forces of gravity causing swelling or squeezing ground, or downward settlement of broken rock.
2. Major bedrock slides from causes other than earthquakes.
3. Fault displacement across the tunnel.
4. Major damage due to earthquakes.

Tunnel failure due to forces of gravity or bedrock slides is a consequence of inadequate exploration and/or improper design. These hazards can be eliminated. The hazards of fault displacement and major damage from earthquakes require more serious consideration and are discussed in later sections.

In the present case, there is the additional possibility of bedrock deformation in excess of the desired operating tolerances. However, this is more of an operational problem than a hazard which affects the feasibility of the site, and it will not be discussed in this report. The possibility of such crustal deformation exceeding the allowable tolerance of 5 feet in a distance of only 2 miles is extremely remote.

NATURE OF EARTHQUAKES

Earthquakes are caused by movements in the earth's crust. Minor earthquakes may be associated with volcanic activity or landslides, but all large earthquakes are caused by the movements of blocks of the crust along deep-seated fractures called faults. The destructive earthquakes are associated with movements along major faults and usually originate at depths of 10 to 25 miles below the surface (10)*.

The generally accepted mechanism of fault earthquakes is defined by the "elastic rebound theory" proposed by Reid in 1910 (11)*. According to this theory, the crustal blocks on opposite sides of an active fault are in continual motion. This movement causes bending or straining of the rocks within the blocks. When the accumulated strain exceeds the frictional resistance along the fault, a failure occurs and the rocks on opposite sides of the fault snap back to their original unstrained positions. This snapping action, and the rubbing due to differential movement of the rocks along the fault plane, generate the vibrations that constitute an earthquake. Aftershocks originate in the same way except that the strain of the rocks is accumulated quickly as a result of the movements along the master fault. The point on the surface of a fault plane at which active slipping first takes place is called the focus. The point on the surface of the earth immediately above the focus is termed the epicenter. These points may be determined instrumentally, but it should be realized that the energy release and intensity of shaking may be distributed along the entire active segment of the fault.

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*Numbers in parenthesis refer to specific publication list in Appendix F.

The magnitude of an earthquake is an instrumentally determined quantity which was originally derived by Dr. C. F. Richter to measure the total released energy. The intensity of an earthquake varies with location and is a measure of the destructive power of the shaking. The various intensity scales are based on the arbitrary evaluation of the effects of an earthquake as defined by sensory observation and by the extent of damage to structures (10)*.

The two types of destructive vibrations resulting from earthquakes are longitudinal waves (P) and transverse waves (S). The P waves are the faster and radiate maximum energy along the plane of the fault. The slower S waves radiate maximum energy in a direction perpendicular to the fault plane (10)*. The destructive power of the wave motion depends on the amplitude, frequency, and duration of the vibrations, with the S waves generally being the most destructive. Close to the fault line the P waves may be extremely destructive, but their energy decreases rapidly away from the fault. For any given wave, the amplitude of ground vibration varies greatly with the type surface material that is involved, and may be many times greater in alluvium than in solid bedrock. The intensity of shaking in water saturated alluvium may be 10 or 15 times as great as that in the underlying bedrock (see Appendix B).

Earthquakes may occur in any part of the world but the major destructive earthquakes are concentrated in two belts, one along the Mediterranean-Himalayan axis, and the other in the mountainous areas bordering the Pacific Ocean. The West Coast of the United States, and particularly California and

*Numbers in parenthesis refer to specific publication list in Appendix F.

Nevada, lie within this latter zone of activity. It has been estimated that 2½% of the earthquakes in the world and 95% of those in the United States (not including Alaska) occur in California and Nevada (2)*.

At present, there is no way to predict accurately the time of occurrence or the magnitude of future earthquakes. According to Dr. Perry Byerly (personal communication, July 7, 1959), there is insufficient evidence in the historical record to support the theory of cyclical reoccurrence of earthquakes in any given locality. The recent occurrence of a strong earthquake in a given area may be evidence that dangerous accumulated strain has been released, but it is equal proof that the area affected is one in which strain has accumulated in the past and will probably accumulate in the future. In like manner, the historical absence of a severe earthquake in an area of known seismicity, and along the line of a known active fault, may be evidence of a dangerous strain build-up but it may also indicate that strain is not accumulating but is being constantly released by gradual fault movements. Future progress in seismology and geodesy will probably provide the solutions to these uncertainties. At the present time, however, the problem of predicting earthquakes, especially as it affects construction progress, must rest on the assumption that the future will resemble the past and preventive measures must be taken accordingly.

Types of Earthquake Damage

Damage during earthquakes may result either from the movements along the fault plane or from the vibrations associated with these movements.

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*Numbers in parenthesis refer to specific publication list in Appendix F.

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According to Dr. C. F. Richter, of the California Institute of Technology, throughout the World there are only about 20 instances of proven surface rupture of bedrock which can be correlated with known earthquakes (10)*. Such ruptures have occurred as features of only the most destructive earthquakes and then only along the traces of faults which may be recognized as having been active in recent geologic time. In the usual case, the actual movement along the fault dies out before the surface is reached. In cases when surface rupture does occur, damage will consist of rifting and offsetting of roads, fences, pipelines, tunnels, dams and other structures which cross the trace of the fault. Such damage is usually severe but it is easily avoided by locating structures away from the traces of known active faults.

The strong vibrations of earthquakes may directly cause damage or destruction to structures and equipment, or they may trigger a variety of secondary effects which may also eventually result in damage to the works of man. The usual secondary effects are landsliding, and in alluvium or filled ground, slumping, lurching, and formation of pressure ridges. These latter effects are distinct from bedrock rupture. Landslides may occur in areas with deep soil cover, weak broken or sheared rocks, steep topography, and water saturated material. They are caused by the force of gravity acting on an unstable mass and are merely triggered by the earthquake vibrations. Landslides may uncover or crush tunnels, block roads and streams, or cover buildings. Landslides generally occur in areas where past landsliding has left recognizable features. Such areas should be avoided as construction sites if at all possible.

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*Numbers in parenthesis refer to specific publication list in Appendix F.

Severe earthquake shaking of deep alluvium or artificial fill, especially when these are water saturated, may cause differential settling or spontaneous liquification. These phenomena result in the formation of cracks, ridges, and depressions, and in the occurrence of slumping and earth flow. When large structures must be built on alluvium, expensive foundation preparation, such as piling and grouting, is necessary.

With an earthquake of given character and magnitude, the severity of vibration damage to a structure will depend primarily on three factors: 1) distance from the epicenter or from the active segment of the fault; 2) type of engineering structure; and 3) the geologic foundation on which the structure is built. Within the area of destructive intensity, the factor of distance is probably the least critical.

In general, the resistance to earthquake damage is greatest in well-designed structures of reinforced concrete and least in buildings of unsupported masonry. Modern earthquake-proof structures are designed to resist the horizontal accelerations caused by earth vibration. They often incorporate design features to dampen structural vibration frequencies and large structures may include provision for differential movement between their various sections during severe shaking (10) (8) (3)*.

From the standpoint of earthquake resistant construction, the best possible foundation is sound strong bedrock and the worst is water-saturated alluvium, with all gradations being found between these extremes. The importance of foundation is shown by the many recorded cases of only slight

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*Numbers in parenthesis refer to specific publication list in Appendix F.

damage to relatively weak frame and masonry buildings built on bedrock when, in the same earthquake, stronger structures built on alluvium were seriously damaged or destroyed, even when the latter were at a greater distance from the fault (10) (8)*.

*Numbers in parenthesis refer to specific publication list in Appendix F.

EARTHQUAKES IN THE SAN FRANCISCO BAY REGION

Many of the major earthquakes of California occur along a belt of northwest trending faults which extends from the Imperial Valley to the Northern Coast Ranges. The San Francisco Bay Region is transected by several of these major fractures. The Hayward and Calaveras faults extend through the eastern part of the Bay Area and the San Andreas Fault runs diagonally across the San Francisco peninsula. There may be another large active fault buried under the sediments of the bay and the Santa Clara Valley. These faults extend deep into the crust of the earth and are major structural features which are independent of smaller local structures. It has been established by observation of offset fences, roads, streams, and ridge lines that the movements on these faults is essentially horizontal, with the block on the west side of the fault moving northward with respect to the block on the east side of the fault. These movements have been confirmed by repeated measurements by the United States Coast and Geodetic Survey but the exact rate of movement, although about 2 inches per year between points 40 to 50 miles apart, has not been determined accurately (15) (16)*.

There is continual seismic activity, most of it very minor, associated with the fault systems of the San Francisco Bay Region. The general area is recognized by Dr. Byerly (2)* as the seismically most active region in California and has been classified by Dr. Richter (12)* as the most hazardous earthquake area in the United States. This hazard is generally recognized, and major engineering structures in the Bay Area are designed to withstand the effects of strong earthquakes.

The extent of seismic activity in the Bay Area may be seen by examining the plot of epicenters bound in this report as Appendix A. The

*Numbers in parenthesis refer to specific publication list in Appendix F.

larger earthquakes are located near the major fault lines, but the minor activity is widespread and, in many cases, is not associated with fault lines that can be mapped at the surface. This record of epicenters reveals that the areas of greatest seismic activity are concentrated east of the Bay and in the Santa Clara Valley. The southern part of the San Francisco peninsula, within a radius 15 or 20 miles of the proposed tunnel site, was remarkably free of epicenters during the recorded period.

The two most recent major destructive earthquakes in the area occurred in 1868 and 1906 and were caused by movement on the Hayward and San Andreas Faults respectively. Since 1906 some damage over limited areas has been caused by smaller earthquakes such as the 1933 Niles earthquake, and the 1937 Berkeley earthquake, and the 1957 Daly City earthquake (6)*. Surface ruptures were observed only in the two major earthquakes and then only along the main fault trace. The 1906 earthquake was by far the most destructive. Widespread damage to structures occurred throughout the region, particularly at Santa Rosa, San Francisco, Stanford University and San Jose.

About half of the City of San Francisco was destroyed, but only 20% of the destruction was due to the earthquake. The remaining 80% resulted from the great fire which followed the earthquake. The subsequent analysis of structural damage revealed that most of the buildings which were severely damaged were poorly designed, poorly constructed, and built on deep water-saturated artificial fill. Buildings on the rocky hills suffered comparatively minor damage. Properly designed structures on alluvium, even when they were of masonry construction, resisted the earthquake successfully (8) (3)*.

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*Numbers in parenthesis refer to specific publication list in Appendix F.

A distinctive feature of the 1906 earthquake was a 270-mile surface rupture along the trace of the San Andreas Fault, which offset many natural and man-made features. The maximum horizontal offset was 21 feet. Two brick-lined railroad tunnels, which crossed the fault in the Santa Cruz Mountains, were offset and partially destroyed. The intensity of the initial shock wave near the fault was sufficiently severe to uproot oak trees and snap the tops off redwoods (8)*.

Stanford University is located 4½ miles from the San Andreas Fault. Most of the buildings were of unsupported masonry construction and were built on fairly deep natural alluvium. The one- and two-story buildings were scarcely affected, but the arcades and several of the 3- and 4-story buildings suffered severe damage. However, in view of the unfavorable combination of masonry construction and alluvial foundation, it is remarkable that the majority of the buildings suffered only minor damage. Analysis of the Stanford damage revealed that most of the seriously damaged buildings were inadequately designed and poorly constructed even to the extent that inferior mortar had been used (8)*.

As a result of the 1906 earthquake, engineering designs have been developed which result in virtual earthquake-proof construction. Major engineering works built in the San Francisco Bay Region since 1906 include the Broadway and Twin Peaks tunnels, the Oakland-Alameda submarine tunnel, numerous tall buildings in San Francisco and Oakland, several tunnels of the Hetch-Hetchy aqueduct, and the Golden Gate, Oakland-Bay, and Richmond bridges.

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*Numbers in parenthesis refer to specific publication list in Appendix F.

As stated previously, the accurate prediction of earthquakes is impossible with present knowledge. However, in the San Francisco Bay Region, with its history of earthquakes, seismic activity, and measurable crustal movement (2) (6) (15)*, it may be stated positively that major earthquakes will occur in the future, but that the time of occurrence is indeterminate. It may be assumed that the intensities of future earthquakes can be similar to, but will not exceed greatly, those of the 1906 earthquake.

*Numbers in parenthesis refer to specific publication list in Appendix F.

EFFECTS OF EARTHQUAKES ON TUNNELS

Review of the literature thus far has revealed only a few instances of earthquake damage to tunnels, principally railroad tunnels, affected during the 1906 San Francisco earthquake (8)* and the 1952 Kern County earthquakes (10)*. A more exhaustive survey of world-wide occurrence of earthquake damage to tunnels by C. M. Duke and D. J. Leeds, in an unpublished report for the second RAND symposium on protective construction, described two other cases. These involved damage to railroad tunnels in Japan during the 1923 Tokyo earthquake and the 1930 Tanna earthquake. In all of these cases, the damage occurred to unlined or poorly supported tunnels or to reinforced tunnels driven through incompetent broken rock in areas of steep topography. In each case either the active fault producing the earthquake passed across the tunnel, or the tunnel was located in the immediate epicentral area of the earthquake.

It is significant that there are several reported cases where major earthquake damage occurred at the surface, while miners working beneath the same area did not even notice the earthquake (3)*. It has been confirmed instrumentally that the amplitude or displacement of certain types of earthquake vibrations exhibit a marked decrease in depth. Depending on the types of materials involved, the ratio displacements may be as great as 10, or even 15.

In this respect, the summary and conclusions in the RAND Symposium report are partinent to the appraisal of tunnel site feasibility. The text of the report is bound as Appendix B.

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*Numbers in parenthesis refer to specific publication list in Appendix F.

TUNNELS IN CALIFORNIA

A partial list of California water tunnels is bound as Appendix C. The list was obtained from the California State Department of Water Resources and includes only tunnels over 1,000 feet in length; it shows the tunnel name, location, bore, length, and date completed. A similar list of highway and railroad tunnels is being compiled.

There are over 100 major water tunnels in the state, totaling over 300 miles in length. Many of these tunnels are located in particularly hazardous earthquake areas, and have experienced strong earthquake vibrations. A number of the tunnels cross known active faults. It is significant that there are no known cases of failure in these water tunnels due to earthquakes.

The Los Angeles Metropolitan Water District owns and operates 142 tunnels totaling 43 miles in length; the Pacific Gas and Electric Company owns and operates 73 tunnels totaling 143 miles in length; and the San Francisco Metropolitan Water District owns and operates 34 tunnels totaling 76 miles in length. None of these companies have ever experienced significant earthquake damage in their tunnels (See Appendix B).

According to Mr. J. H. Turner, Chief Engineer and General Manager (personal communication, July 19, 1959), the San Francisco Water Department owns and operates 29 tunnels in the Bay Region, all within 50 miles of San Francisco. Many of these tunnels were built in the 1870's and are brick lined. These old tunnels went through the 1906 earthquake and suffered no damage, despite the fact that several were located only a short distance from the San Andreas Fault.

GENERAL GEOLOGY

Regional Geology

The proposed accelerator site is located in the gently rolling foothills along the eastern side of the San Francisco peninsula. The surrounding area is characterized by northwest-trending topography which roughly reflects the structure and distribution of the underlying rocks. The major feature of the region is the San Andreas Rift Zone which lies approximately four miles southwest of the project site. This zone extends north-northwest diagonally across the San Francisco peninsula. The rocks and structures on opposite sides of the San Andreas Fault are distinctly different. Since no structures extend across the rift, only the geology east of the zone is described in this report.

The oldest rocks in the region are of Jurrasic age and belong to the Franciscan Formation. This formation is a major unit in the Coast Ranges and is characterized by complex structures and diverse rock types. In the western part of the area these rocks are at or near the surface and in the eastern part of the area are overlain by folded sandstones, shales, limestones and lavas of Tertiary age. The tunnel will be driven through the latter rocks.

The major structural features in the western part of the area are strongly developed branching faults which diverge from the San Andreas Rift Zone and extend southeast across the area. The nearest of these large faults passes within 1½ miles of the project site. The Tertiary rocks in the eastern part of the area are moderately folded and are cut by faults which also trend northwest to southeast. These latter faults are less well developed and less continuous than the parallel faults to the west. The area is bounded on the east by the alluvial apron bordering San Francisco Bay.

Local Geology

The site geology was mapped by Stanford graduate students in 1956 under the supervision of Prof. B. M. Page. The mapping included earlier work by the writer, Frank Atchley. The geologic report is bound as Appendix D.

The principal rocks in the area consist of relatively weak shales and sandstones unconformably overlain by a local sequence of hard resistant basalts and weak volcanic agglomerates. These volcanics, in turn, are overlain by massive friable sandstones and lenses of hard sandy limestone. These rocks are of Tertiary age and, although tilted and folded, are relatively undeformed. They will provide better tunneling conditions than generally found elsewhere in the Coast Ranges, especially in the serpentines and deformed rocks of the Franciscan Formation.

There undoubtedly will be local troublesome sheared zones which are concealed, but generally speaking the rocks are sound and competent.

The over-all structure in the eastern half of the area is an eroded plunging anticline or dome which is locally modified by faulting. Structure in the western half of the area is essentially a tilted succession of strata dipping generally 35-60 degrees to the south and forming the south limb of the anticline. There are at least three discontinuous faults in the general area, but only one of these is known to cross the presently proposed tunnel line.

The tunnel line passes under the plunging end of the dome through more or less horizontal strata and then continues westward, crossing the tilted strata at an oblique angle. The principal rocks which will be encountered will be shales and sandstones.

APPRAISAL OF PROJECT HAZARDS

The proposed project will operate on a continuous 24-hour basis and there will be personnel at work in the control tunnel at all times. There will be expensive delicate equipment and rather heavy machinery located in the tunnels and target buildings. Once the accelerator is in operation, an interruption would involve large monetary loss.

The above features require particularly safe tunnels and necessitate concrete lining throughout. Adequate design measures will insure against the possibility of tunnel collapse, or rock slides in the portal areas. Thus, the only natural hazard which could interrupt the operation is major earthquake damage.

Earthquake damage may result from severe shaking or from fault displacement. Damage could occur to the tunnels, to the appurtenant buildings on the surface, or to equipment within these structures. The worst possible damage would be direct fault offset across the tunnel, with displacement greater than that which could be counteracted by adjusting the accelerator mountings. The next greatest hazard would be severe damage from toppling equipment, cracking of tunnel walls, local collapse, or structural damage at the surface.

Regarding the possibility of fault displacement, it has been shown that throughout the world there are only about 20 established cases of surface bedrock rupture accompanying an earthquake. Moreover, there have been no known instances of bedrock rupture except along the trace of recognized major active fault zones. In the Bay Area the only known bedrock ruptures have been along the Hayward Fault in the 1868 earthquake and along the San Andreas Fault in the 1906 earthquake. This evidence indicates that

there is but slight chance of a new fault break ever occurring in any given small area, particularly if no active faults cross the area. In the project area, mapping has revealed the presence of one fault crossing the proposed tunnel line. There is no indication that movements have ever taken place on these faults in historical or geologically recent time. Based on this evidence, it appears that the hazard of fault displacement across the tunnels is negligible.

Regarding the possibility of earthquake damage due to severe shaking, it has been shown that the danger of damage to properly designed tunnels is less than the danger of damage to structures on the surface. This is particularly so when the tunnels are not crossed by active faults. The most likely hazard would be from toppling and shifting of machinery and equipment within the tunnels. This danger can be minimized by the use of proper mountings. The danger from rockslides and shifting rock, which could cause collapse or cracking of the tunnel walls, is quite small at the proposed site because of the presence of competent rock and gentle topography.

Minimizing the danger of earthquake damage to surface structures is a matter of selecting the best possible foundations and then designing accordingly. The present planned tunnel alignment is such that all critical structures are founded on bedrock. For structure design, it is necessary to estimate the horizontal acceleration that could result from an earthquake of expectable magnitude and establish a seismic factor of safety that is commensurate with reasonable risk.

APPENDICES

A. MAP OF EARTHQUAKE EPICENTERS IN THE SAN FRANCISCO AREA

B. EFFECTS OF EARTHQUAKES ON TUNNELS, by D. M. Duke and D. J. Leeds

C. LIST OF CALIFORNIA WATER TUNNELS

D. ENGINEERING GEOLOGY OF THE PROPOSED SITE OF PROJECT "M", STANFORD, CALIFORNIA, by H. C. Langerfeldt and L. W. Vigrass

E. ENGINEERING COMPANY SUMMARY REPORTS

   1. Utah Construction Company
   2. Bechtel Corporation
   3. Kaiser Engineers

F. SELECTED REFERENCES

APPENDIX A

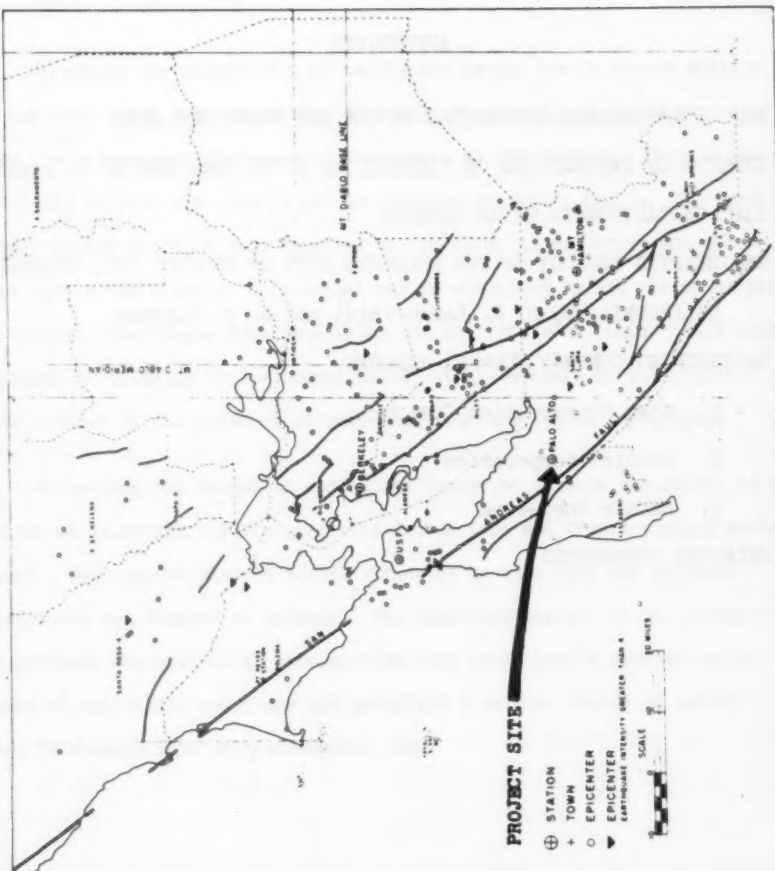

FIG. 20. Map of San Francisco Bay area showing principal active faults (heavy black lines) and the epicenters of earthquakes that occurred during the periods 1906-41 and 1947-48. The intensity of the various shocks is shown by the epicenter symbols listed in the legend to the left of the map.

APPENDIX B

April 1, 1959

EFFECTS OF EARTHQUAKES ON TUNNELS

by C. M. Duke and D. J. Leeds*

(Manuscript draft without illustrations)

Introduction

An effort is made here to summarize and generalize the available information on earthquake damage to tunnels. Four reasonably well documented cases are presented, along with supporting and indirect evidence. The details of the failures and of the geology are less complete than is desirable, but the facts available appear to warrant several useful generalizations. The original sources cited may be consulted by those wishing to study the data in detail.

Experience in California and Japan

Central California, 1906. In the San Francisco earthquake of 1906 there were two damaged tunnels on the narrow-gage Southern Pacific Railroad between Los Gatos and Santa Cruz. The 6200-foot tunnel at Wright Station was crossed by the San Andreas fault and the 5700-foot tunnel directly to the south was also damaged, but to a somewhat lesser degree. Shaking at the surface over the tunnels was very intense, designated 10 on the Rossi-Forel scale. Damage to the tunnels themselves, Table I, consisted of the caving in of rock from the roof and sides, the breaking in flexure of upright timbers, and the upward heaving of rails and breaking of ties. Both tunnels were blocked at a number of points.

The tunnel at Wright Station suffered a 4.5 foot transverse horizontal offset where the fault cut it. See Fig. 1. This same movement wrecked the Morrell house which stood above the tunnel and on the fault. Tunnel damage was greatest around the offset and at the several locations where parallel fissures were in evidence.

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Fig. 2b1. Map of San Francisco Bay area showing principal active faults (heavy black lines) and the epicenters of earthquakes that occurred during the periods 1769-1841 and 1842-48. The intensity of the various shocks is shown by the epicenter symbols listed in the legend to the left of the map.

The rocks in the Wright tunnel looked like sandstones and jaspers of Franciscan age

Other tunnels on the Santa Cruz-Los Gatos line were undamaged, except for two cases of broken timbers. New tunnels under construction on the Bayshore line, in southern San Francisco, were uninjured.

Tokyo Area, Japan, 1923. The great 1923 earthquake damaged about 25 tunnels, Table II, in the vicinity of Tokyo, principally on the Izu and Boso peninsulas which are the mainland areas closest to the epicenter. The damage is attributed to shaking, as no case of faults intersecting the tunnels is known. Most of the tunnels were concrete or brick lined, with depth of cover, character of rock, length, and other features varying over a rather wide range. Particularly heavy tunnel damage occurred in the Odawara-Atami-Hakone region, which suffered the highest intensity of shaking. Beyond the isoseismal corresponding to approximately 50% of houses collapsed, tunnel damage apparently was insignificant.

Figures 2 through 6 illustrate the destruction in two selected cases. Damage varies from fractured portal masonry through cracked linings to caveins from roof and sides.

Tanna, Japan, 1930. The Tanna Tunnel, connecting Atami and Mishima, was under construction during the Izu earthquakes in 1930. The Tanna fault intersected one of the drain tunnels which extended ahead of the main tunnel heading, causing a transverse horizontal offset of 7.5 feet at a distance of about two feet beyond the main tunnel heading. See Figs. 7 and 8. The only damage to the tunnel was a few cracks in the walls. But in the village of Karuizawa, situated on the Tanna basin 160 meters above the tunnel, 55% of the dwellings were thrown down, and 40% of the houses were destroyed at the nearby villages of Tanna and Hata. Surface displacements on the fault occurred over a distance of 15 kilometers.

The Tanna basin is a lake deposit of sandy clay and boulders, about 40 meters deep, overlying andesite and agglomerate through which the tunnel passes.

Kern County, California, 1952. The Kern County earthquake of 1952 severly damaged four tunnels, Table III, on the Southern Pacific Railroad near Bealville, about 15 miles northwest of Tehachapi. This was the region of largest observed ground fractures associated with movement on the White Wolf fault. See Figures 9 and 10. In all, there were 15 tunnels between Bakersfield and Tehachapi, and those outside of but adjacent to the area of ground fractures suffered slightly, to the extent of opening of construction joints. The railroad in this area was built in about 1876, with timber lining in the tunnels. Reinforced concrete lining 12 to 24 inches thick was installed later, without removing the timber. Rock around the four damaged tunnels was a fairly easily excavated decomposed diorite.

Tunnel No. 3, originally 700 feet long, was heavily damaged at its Tehachapi end, 200 feet of which was daylighted after the quake. See Figs. 11 and 12. At one place the buckled rail extended under the concrete wall, indicating that the wall had raised sufficiently to permit this. While ground cracks were not found directly over No. 3, an active fault crossing the tunnel was found during daylighting.

Large surface cracks, Fig. 13, were found above No. 4, which was badly shattered, Fig. 14, and subsequently daylighted for its full length.

Tunnel No. 5 was very heavily damaged, Fig. 15, but was reconstructed without daylighting. Cracks and holes appeared in the ground above, and rock and soil from these cracks flowed into the tunnel.

Broken lining comprised the damage to No. 6, Fig. 16, which was daylighted. No substantial surface cracking was noted over this tunnel.

These tunnels were in the region of heaviest shaking, Modified Mercalli Intensity II, but clearly the extensive damage was primarily due to their location in the fault zone.

Fukui 1948 and Hokkaido 1952. At Kumasaka, north of Kanazu, the portal arches of a brick-lined tunnel were partially fractured in the 1948 Fukui earthquake. Also in this earthquake, a large concrete culvert was badly cracked at midlength.

In the 1952 Hokkaido earthquake, minor cracking was induced in the walls of one concrete-lined and one brick-lined tunnel.

Fault movement at the tunnels was not involved in the above cases.

Related Experience

Mines and Caves. During the Sonora earthquake of 1887, an engineer was in a mine at Tombstone, Arizona. He felt violent shaking and observed small rockfalls, but no collapsing, down to several hundred feet of depth. Most stopes were untimbered. Damage on the surface consisted of falling plaster and chimneys, and shifting of engines on their foundations.

In another case, in mines at Butte and Barker, Montana, the 1925 earthquake was hardly noticed by those underground but was felt at the surface.

The August 22, 1952, Kern County aftershock was reported not to have been felt by a party in Crystal Cave, Sequoia, but to have been sharply felt by persons outside the cave.

There appears to be a possibility that rock bursts at Widwatersrand, South Africa, may be triggered by releases of energy at points in the mine complex away from the bursts.

Experience of California Agencies. Correspondence from W. M. Jaekle, Chief Engineer, Southern Pacific Company, reveals that, except for the 1906 and the 1952 cases, no damage or disturbance to Southern Pacific tunnels has been caused by earthquakes.

The Los Angeles Department of Water and Power operates the Owens Valley Aqueduct, which includes 142 tunnels totaling 43 miles in length. The Aqueduct was completed in 1911, and no tunnel damage due to earthquakes has occurred. The Elizabeth Tunnel, five miles long, crosses 3000 feet of the San Andreas rift zone at a depth of up to 1000 feet. It is inspected annually; no earthquake damage has been found to date.

The Pacific Gas and Electric Company has experienced no significant earthquake damage to tunnels in its 40 years of experience with 73 tunnels, unlined and concrete lined, totaling 119 miles in length.

The above experiences are significant in view of the fact that California has experienced severe earthquakes in 1915 (Imperial Valley), 1925 (Santa Barbara), 1933 (Long Beach), 1940 (El Centro), 1952 (Kern County), and 1954 (Western Nevada), in addition to the great earthquake of 1906.

Effect of Depth below Surface. Several Japanese investigators have measured small earthquake motion at some depth and simultaneously at the ground surface. Omori (1902) was the first to make such measurements. Nasu determined the ratios of displacements of 14 earthquakes at the surface above Tanna Tunnel and in the tunnel at 160 meters depth to be 4, 2, 1.5, 1.2 for periods 0.3, 1, 2, 5 seconds, respectively. The ground was lake deposits at the surface and andesite and agglomerate at depth. Saita and Suzuki found that the maximum acceleration at the surface of a 68-foot layer of alluvium was three to five times that at its base contact with diluvium. Inouye found that short-period waves (ripples) observed at the surface were largely absent at a 9-meter depth.

Carder of the U.S. Coast and Geodetic Survey recorded approximately equal amplitudes of microseisms at the surface and at 5000-foot depth in Homestake Mine. Microseisms were of four or five second period. In a later study, earthquake P-waves of one-second period were recorded at 300-foot depth with twice the

amplitude recorded at 5000-foot depth.

Recently, Kanai has made signal progress in this field. He operated seismographs at depths of 0, 150, 300, 450, and 600 meters in a copper mine in Hitachi and recorded a very large number of small earthquakes. The ground is paleozoic rock, with some weathering near the surface. The ratio of surface maximum displacement to that at 300 meters depth was about 6 at the mine and about 10 at a school 6 kilometers away on alluvium. Earthquakes whose average period of incoming waves was close to the free period of the surface layer caused these maximum ratios, but many earthquakes occurred for which the ratios were as small as one-third of the above. He also found that the period of the short-period waves (ripples), found on surface seismograms but not underground, corresponds to the predominant period of the surface layer; the ripples dominated the surface record when the incoming waves contained components with period equal to that of the ripples. These findings support quantitatively the theoretical amplification formulas of Sezawa and Kanai.

Qualitatively, these researches demonstrate experimentally the following effects of depth:

a. At short periods, surface displacements are larger than underground displacements.

b. The ratio of surface to underground displacement depends on the type of ground. It is greater for alluvium than for weathered rock. It may reach a value of at least 10.

c. For wave periods over one second, the ratio becomes comparatively small, approaching unity as the period increases.

d. There is a particular average period of incoming waves for which a given type of ground will provide a maximum ratio of surface to underground displacement. If the average period of incoming waves is not approximately equal to this particular period, the ratio will be materially smaller.

Generalizations

1. Severe tunnel damage appears to be inevitable when the tunnel is crossed by a fault or fault fissure which slips during the earthquake.
2. In tunnels away from fault breaks, severe damage may be done by shaking to linings and portals and to the surrounding rock, for tunnels in the epicentral region of strong earthquakes, where construction is of marginal quality. Substantial reinforced concrete lining has proved superior to plain concrete, masonry, brick, and timber in this regard.
3. Tunnels outside the epicentral region, and well constructed tunnels in this region but away from fault breaks, can be expected to suffer little or no damage in strong earthquakes.
4. While it would seem reasonable that competence of the surrounding rock would reduce the likelihood of damage due to shaking, inadequate comparative evidence is available on this point.
5. Within the usual range of destructive earthquake periods, intensity of shaking below ground is less severe than on the surface.

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APPENDIX C

CALIFORNIA WATER TUNNELS

The following list of California tunnels was obtained from the State Division of Water Resources. It is a partial list of water tunnels only, and the data is not complete. It is estimated there are approximately 50 highway and railroad tunnels in existence over 1,000 feet in length.

NAME	LOCATION	DATE	BORE	LENGTH
Gibralta Reservoir	nr Santa Barbara	prior 1942	7' x 9'	6 miles
Juneal Reservoir	nr Santa Barbara	prior 1942	7' x 9'	4 miles
Mono Crater	nr Levining	1939	12'	59,813 ft.
Tecolote	nr Santa Barbara	1955	9'	33,557
Kerckhow	Fresno County	1920	18'	8,350
Pit No. 1	Shasta County	1922	16'	10,000
Pit No. 3	" "	1925	22'	20,900
Pit 5 No. 5	" "	1944	21'	5,837
Pit 5 No. 2	" "	1944	21' x 21'	23,161
Pit No. 4	" "	1954	21' x 21'	21,434
Balch	Fresno County	1924	12'	19,000
Bucks Creek No. 1	Plumas County	1925	7' x 9'	9,330
Bucks Diversion	Plumas County	1925	8'	5,750
Melones	(?)	1927	13.5'	4,960
Drum Canal No. 1	Nevada County	1928	10' x 14'	3,350
Tiger Conduit	Amador County	1932	10' x 11'	14,350
Stanislaus	Tuolumne County	1939	9.5' x 10'	57,308
Colgate	Yuba County	1940	9' x 10'	24,674
Oleum	Contra Costa	1942	10' x 11'	2,578
Dutch Flat	Placer County	1943	12' x 12'	21,755
Narrows	Nevada County	1943	11' x 14'	1,056
Tabeaud	(?)	1948	14' x 14'	2,869
West Point	Amador County	1948	13' x 15'	14,333
Electra	Amador County	1949	13' x 14'	43,062
Cresta	Butte County	1949	23' x 26'	20,903
Rock Creek	Plumas County	1950	25' x 25'	34,019
Bear River Dam	Amador County	1952	10' x 12'	1,095
Bear River	Placer County	1952	8.5' x 11'	13,249
Hendricks	in Sierra Mts. (?)	1953	7.5' x 8'	4,620
Wishon	Madera County	1956	15' x 15'	11,038
Poe	Butte County	1958	24' x 24'	32,834
Butte Valley	Lassen County	1958	15' x 15'	10,899
Caribou No. 2	Plumas County	1958	15' x 15'	8,710
Hass	Fresno County	1958	13' x 13'	32,854
Contra Costa No. 1	Contra Costa County	1939	9'	1,360
Lake Merced	(?)	1949	10'	2,700
San Pablo	Contra Costa County	(?)	(?)	3 miles
Claremont	" " "	(?)	(?)	5 miles
Walnut Creek	" " "	(?)	(?)	2,500 ft.
Feather River	Plumas County	(?)	25'	7 miles

NAME	LOCATION	DATE	BORE	LENGTH
Colorado River Aqueduct System				
Colorado River	various	1939	19'	1 mile
Coojan Basin	"	"	"	1
Whipple Mt.	"	"	"	7
Iron Mt. East & West(2)		"	"	8
Cocks Comb	"	"	"	3
East Eagle System (3)	"	"	"	7
Hayfield No. 1 & 2(2)	"	"	"	3
Cottonwood	"	"	"	4
Mesa Pass and Cochella Mt. System (10)	"	"	"	20
Uvalde	"	"	"	8
San Jacinto	"	"	"	13
San Diego Aqueduct System				
Rainbow	various	1946	6' lined	4,700 ft.
Red Mountain	"	1949	" "	3,078
Oak Hill	"	1947	" "	3,590
Bowry	"	1947	" "	3,180
Five Hill	"	1946	" "	5,700
San Vicente	"	1946	" "	2,455
Hetch Hetchy Aqueduct System				
Sierra Division (essentially one tunnel with short gaps)	various	various	14' x 14'	99,264 ft.
Coast Division (essentially one tunnel with short gaps)	"	"	14' x 14'	150,480
Mammoth Pool Aqueduct System				
Florence	various	prior 1930	15' x 15'	13 miles
Florence Lake No. 2	"	" "	21'	67,634 ft.
Big Creek	"	" "	24'	(?)
Mammoth	"	" "	9'	3,008
Owens Valley Aqueduct System				
3 tunnels	(?)	(?)	12'	55,984 ft.

APPENDIX D

ENGINEERING GEOLOGY OF THE PROPOSED SITE OF PROJECT "M" STANFORD, CALIFORNIA

by H. C. Langerfeldt and L. W. Vigrass

under supervision of

Dr. B. M. Page, Stanford University

December, 1956

ENGINEERING GEOLOGY OF THE PROPOSED SITE OF PROJECT "M" STANFORD, CALIFORNIA

SUMMARY AND RECOMMENDATIONS

In the area proposed as a site for Project "M", Eocene sandstone, mudstone and shale dip steeply southwesterly and are bounded to the west, south and east by more gently dipping miocene basalt, fragmental volcanic rock, limestone, sandstone and minor shale. Several faults, showing no evidence of recent movement, cut across this semi-domal structure.

From a geologic viewpoint, the site has no serious engineering problems. Indications are that blasting costs will not be excessive. Tunnel support will be required, but running ground is not anticipated in the tunnel section. Danger of landslides is minimized by the general dip of the beds into the slope. Groundwater may be a problem locally but no serious flooding problem is expected.

Since the geologic data presently available is inadequate for a report which is in any way complete, it is recommended that an exploration program designed to test the engineering properties of the rocks to be cut or tunnelled be undertaken before construction plans are finalized. It is further recommended that the areas selected for use as fill material be test drilled prior to final location of the borrow pits.

INTRODUCTION AND PURPOSE

This report covers the geology of an area of the foothills west of Stanford University campus which has been tentatively selected as the site for the proposed two-mile linear accelerator, referred to as Project "M". This report is part of a study of the general feasibility of the site and its threefold purpose is: (1) to study the geological suitability of this area for the project; (2) to aid the engineers in estimating the cost of excavations; and (3) to direct attention to special problems which may result from geologic conditions at the site.

LOCATION

The area investigated lies in Santa Clara and San Mateo counties and has the form of a northwest trending strip, one-half mile wide by three miles long. It is approximately bounded to the northeast by Junipero Serra Boulevard, to the west by Alpine Road, to the southwest by the crest of the easternmost range of hills, and to the east by Fremont Avenue.

PHYSIOGRAPHY

The area is on the northeastern slope of low foothills of the California Coast Ranges which border San Francisco Bay to the west. This range of hills in the mapped area reaches maximum elevations of about 500 feet along the ridge line bounding the area to the southwest. The terrain gradually descends northeasterly to the alluvial plain of the San Francisco Bay lowland at elevations of 150 to 200 feet.

Two streams flowing northeastward to San Francisco Bay provide the main drainage. San Francisquito Creek flows in a steep-walled valley near the western boundary of the area. Matadero Creek with one important tributary meanders across an alluvial plain of low relief in the southeastern part of the area. Between these two main drainage-ways, intermittent streams have dissected the range into rounded hills.

Soil cover on the hilltops and slopes probably averages less than one foot. Soil and alluvium in the upper portions of the gullies probably average three or four feet, thickening downstream to about ten feet near the break in slope between the hills and the alluvial flat.

These hills are generally grass-covered with a few oak trees. Some of the steeper ravines are filled with brush.

REGIONAL CONSIDERATIONS

The proposed site of Project "M" lies in an area of faulted and folded late Mesozoic and Tertiary sediments and volcanic rocks. The recently active northwesterly trending San Andreas rift zone lies about three miles to the southwest of the site. The Hayward fault, another recently active fault zone, parallels the San Andreas approximately 20

miles to the northeast of the site. Numerous major and minor faults, with which no recent movement has been definitely linked, also occur in the area.

It is apparent that the proposed site is located in a region of tectonic instability. However, it is impossible to predict when severe earthquakes will occur and what effect they will have on the proposed structure. The tectonic instability of the entire Pacific Coast region should be carefully considered in the selection of a site for this project.

SOURCES OF GEOLOGIC INFORMATION

Probably less than one percent of the area is outcrop. These exposures, generally of the more resistant sandstones, limestones and volcanic rock, occur on top of ridges and in creek beds. Shales and soft sandstones, which are known to be present from excavations, rarely outcrop.

Rocks of the area are exposed in numerous road cuts and several basalt quarries. Several excavations no longer accessible have been described by previous writers.

Information from six holes drilled through the basalt in the southern part of the area was utilized in this report.

Several earlier reports and descriptive notes utilized in this work are listed in the bibliography. The map and several cross-sections prepared by Atchley and Grose (1954) are incorporated directly in this report.

PRESENTATION OF DATA AND INTERPRETATIONS

The map accompanying this report shows exposures of different rock types by black-and-white symbols. Distribution of various rock units as interpreted from these observations and from topography is shown by color. The lack of outcrops, complicated local structure and scarcity of continuous marker beds, make the interpretation of the geology highly speculative, especially in rocks older than the Los Trancos volcanics. The rock units mapped in the Searsville formation indicate only the general characteristics of the rocks and not the exact position of hard and soft sandstones and shales. The units selected for mapping in the Searsville formation are: (1) relatively hard rocks resistant to erosion: mostly hard, well consolidated sandstone but some soft sandstone and shale may be included; (2) rocks of medium hardness: dominantly medium hard sandstone, or interbeds of hard sandstone with soft sandstone and shale; and (3) relatively soft rocks with little resistance to erosion: soft sandstones and/or shales.

STRATIGRAPHY

General

The oldest beds exposed in the area mapped are sandstones and mudstones of Eocene (and Paliocene?) age. These are included in the Searsville formation by Thomas (1949). Overlying these beds with angular discordance are sandstones, volcanic rocks and sandy limestones assigned to the Miocene Los Trancos formation by Thomas. In topographically low areas, the Searsville formation and the Los Trancos formation are overlapped by unconsolidated gravels, sands and clays of the Plio-Pleistocene Santa Clara formation and by Recent alluvium. These youngest deposits have no direct bearing on Project "M" and therefore they have not been mapped or described.

Searsville Formation

The Searsville formation consists of interbedded sandstones, mudstones and shales. In that part of the area traversed by the linear accelerator the formation is about 3000 feet thick. It is estimated that the ratio of sandstone/mudstone is about 4:3. The sandstones are generally feldspathic, thick bedded to massive and medium to coarse grained with a kaolin matrix. They vary in their degree of consolidation from relatively loose, friable and weak to well-cemented with carbonate, hence extremely hard and strong. The argillaceous rocks are commonly yellowish buff, massive mudstone, but some grade to grayish and brownish fissile shales.

Thickness of the interlayers of sand and argillaceous rocks varies from several tens of feet to less than one foot. Although definite evidence is lacking, the difficulty of correlating bed for bed over short distances and the difficulty in tracing marker beds for any distance along strike indicates that lateral variations in lithology within the Searsville formation are common.

Los Trancos Formation

The Los Trancos formation can be conveniently divided into four members from the base upward. Member A: loose to poorly cemented sand; Member B: volcanic rock including basaltic flows and fragmental volcanic material; Member C: coarse fragmental sandy limestone; Member D: soft friable sandstone with rare mudstone layers.

Member A (TlA) overlies the Searsville formation with angular unconformity and underlies the Los Trancos volcanics. It is exposed only on Alpine Road and along San Francisquito Creek where its thickness is estimated at 75 to 100 feet. It consists dominantly of loose to well-cemented medium grained arkosic sand, but may include some coarse bioclastic limestone similar to Member C. It is not known to be present east of the valley of San Francisquito Creek.

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Member B (T1B) consists dominantly of basaltic volcanic rocks which vary in thickness from about 65 feet on Alpine Road to a reported 600 feet along Page Mill Road (Atchley and Grose, 1954). In the western part of the area, the volcanic rock is dominantly aphanitic olivine basalt and vesicular basalt, very strong, hard, and dense where unweathered. In the basalt quarries along Page Mill Road, these flow rocks (T1Bi) form only slightly more than half of the total thickness of volcanic rock. Irregularly interlayered with these flows are bands of fragmental volcanics (T1Bf) which have been variously described as tuff, breccia and agglomerate, but much of which appears to be conglomeratic. Possibly it was deposited as mud flows and land slides from the flanks of active volcanic cones and lava tongues. It consists dominantly of angular to subrounded fragments of volcanic rock, largely basalt, which range in size from less than one inch to several inches in diameter. Many of these fragments appear to have been weathered prior to induration of the rock mass. The fine matrix is not abundant, and although it may be largely altered ash and fine volcanic debris, some fine quartz and feldspathic sand is also present. This fragmental volcanic rock is structurally weak, and near the surface, at least, is badly weathered.

Member C (T1C) is probably less than 50 feet thick. It consists of well-cemented coarse shell fragments ("Barnacle Beds"), with interbedded hard calcareous sandstone. It is hard and relatively strong.

An unknown thickness of soft, buff, fine-grained arkosic sandstone with interbedded soft mudstones and shales directly overlying Member C exposed east of Page Mill Road is assigned to Member D of the Los Trancos formation (T1D). The sandstones of this member are indurated but poorly cemented and friable. Although assigned to the Miocene Los Trancos formation, it may be Pliocene in age.

STRUCTURE

Beds assigned to the Eocene Searsville formation generally strike northwest and dip 40 to 70 degrees to the southwest. The central core of Eocene rocks is bounded on three sides by the Miocene Los Trancos formation which dips away from it at about 10 degrees along the western boundary, and at 30 to 45 degrees along the southern and eastern boundaries.

Faulting complicates this semi-domal structure. A north-south trending fault with upthrown side to the east crosses Junipero Serra near the Matadero Creek bridge and results in the repetition of the Los Trancos volcanics (T1B) and overlying beds. A northwesterly trending fault having its upthrown side to the northeast passes between the two basalt quarries on Page Mill Road but apparently dies out before entering the area of Eocene rocks to the Northwest. A third fault is postulated passing between San Francisquito Creek and the old basalt quarry and trending northeasterly to the junction of Alturas Drive and Junipero Serra Boulevard. This last fault is based on these lines of

inconclusive evidence: (1) offset of bands of resistant beds as expressed by the topography; (2) discordant attitudes of beds of the Searsville formation near the trace of the postulated fault; (3) considerable difference in the general strike of the beds on opposite sides of the postulated fault; and (4) determination of a Paleocene or Early Eocene age for foraminiferal shales outcropping near the entrance to the Stanford Golf Course whereas foraminiferal shales outcropping on Junipero Serra Boulevard 1100 feet southeast of Alturas Drive have been determined as Late Eocene (E. Dean Milou, personal communication).

In addition to these three main faults, numerous smaller faults are doubtless present within the area. Where well exposed in excavations, mudstones and shales show evidence of much shearing and slippage, which however, may have resulted from downhill movement of the rocks or adjustments along bedding planes as a result of folding rather than movement along deep-seated faults.

ENGINEERING PROPERTIES OF THE ROCKS

Excavation

Rock breakage. - An attempt has been made on the map and sections to indicate the amount of blasting required for excavation. It should be emphasized that this is intended to serve as only a rough guide of hardness of the rock units relative to each other, and experience will indicate whether more or less blasting is required.

In construction of the Stanford Tunnel of the Hetch-Hetchy aqueduct, the mudstone and shales were mucked out with pneumatic spades and the sandstones were blasted (Lauenstein, 1951). Hence, it is felt that most or all of the mudstones and shales can be removed without blasting in both the open cut and tunnel. Probably many of the softer sandstones of the Searsville formation can also be removed with shovels, at least in the open cuts. Many of the hard sandstones of the Searsville formation will require blasting. Much of the poorly consolidated and fractured fragmental volcanic rock (T1Bf) probably need not be blasted. The solid basalt flows (T1Bl) will be mostly blasting rock, as will the overlying T1C. The soft sandstones and shales of T1D should be easily moved with a shovel.

Tunnel support. - During construction of the Stanford Tunnel of relatively small diameter (to accommodate 91 inch pipe), continuous installation of supports at four to five foot centers was required to combat swelling and flowage of the shales and mudstones of the Searsville formation. Similarly, the poorly consolidated fragmental volcanics (T1Bf) and the fractured lavas (T1Bl) will require at least some support during driving of the proposed tunnels.

Slopes of open-cuts. - Assuming adequate drainage, it is considered that permanent 1:1 slopes can be maintained in unweathered rock with the possible exception of the loose fragmental volcanic material. With the same exception, most of the other rocks will

probably stand up for a short period of time with a slope as steep as 4:1. The greatest difficulty in keeping cuts open with these side slopes is anticipated where shale beds dip toward rather than away from the excavation.

Landslides

Shearing and local contortions in mudstones and shales of the Searsville formation indicate that they flow easily. Landslides and slips on hillsides underlain by rocks similar to the Searsville formation is a serious problem where the beds dip in the direction of the slope. Fortunately, in the area of the proposed site, the Searsville formation has a dominant southwest dip whereas the slopes are mainly northeasterly. Good drainage is recommended to minimize the danger of slippage along argillaceous strata.

The soil derived from the Searsville formation is clayey and probably highly plastic when wet. It is recommended that this material be stripped prior to placing fill, and that it not be utilized as fill material.

Groundwater

The writers are not aware of good aquifers within the Searsville formation, although some of the hard sandstones, if fractured, may bear large quantities of water. The jointed basalts and fractured fragmental volcanic rocks are known to be excellent aquifers in the area and will probably be locally water-bearing where encountered only by the proposed line of the accelerator. In the Hetch-Hetchy excavations, water control measures were required in hard sandstones overlying the volcanic rocks, but these beds will probably not be encountered in excavations for the accelerator.

Fill Material

The large volume of fill needed near the southeast end of the accelerator can probably be obtained from the elongated hill about one-half mile due south of the intersection of Page Mill Road and Junipero Serra Boulevard. Although outcrops are lacking, the hill is believed to be composed of soft sandstone and shale of Tld. It should be test-drilled before definite plans are made to use it for fill material.

The location of adequate fill material for the western portion of the project requires further study.

Conclusions

Regarding the geologic suitability of the site, it is concluded that:

1. The site is located in the tectonically unstable Pacific Coast region and is about three miles from the recently active San

Andreas fault zone. The location of the project parallel rather than at a high angle to the trend of the San Andreas zone probably reduces the chance of offsetting the line of the accelerator during a major earthquake.

2. Several faults cut through the area of the proposed site. There is no evidence of recent movement along them.

3. There is no indication that costs of excavation of rock cuts and tunnels will be excessively high. Rock breakage costs should be comparatively low. Tunnel support will doubtless be required but there are no indications of extremely loose, running ground. Side slopes of cuts should stand up well.

4. Landslide danger along the argillaceous beds is minimized by the general dip of the Searsville beds into the slope.

5. Groundwater may be a problem locally but no serious flooding of workings is expected.

This paper is to be regarded as a preliminary report since the available geologic information is far from adequate for a complete study of the site. Before construction plans are finalized, a drilling program should be undertaken to explore the portions of the line which are to be cut or tunnelled and engineering tests made on the materials which will be encountered.

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APPENDIX E-1

ENGINEERS CONTRACTORS

UTAH CONSTRUCTION COMPANY

ONE HUNDRED BUSH STREET • SAN FRANCISCO 4, CALIFORNIA
CABLE ADDRESS: UTAHCONCO

July 20, 1959

Mr. F. V. L. Pindar
W. W. Hansen Laboratories of Physics
Stanford University
Stanford, California

Dear Sir:

For several years we have been developing certain information in connection with the proposed construction of the Linear Accelerator. During this period, through discussions and correspondence, we have presented our recommendations on the design and construction of the complete facility. These recommendations, in turn, were based on extensive studies and analyses accomplished by our company, as well as information available on the proposed site prepared by others.

While we understand that construction work on the project will be preceded by the normal exploration, geological and related surveys, it is our opinion that the general proposed area will be feasible for construction and presents no abnormal problems in relation to earthquake hazards.

In that connection we have attached a report prepared by Mr. Clark E. McHuron, our Consulting Engineering Geologist, who has studied this problem and further expresses our views in this matter.

We appreciate the opportunity to present this information.

Very truly yours,

UTAH CONSTRUCTION COMPANY

C. S. Davis
General Vice President

CSD:mf
Attach.

APPENDIX E-1

CLARK E. McHURON
CONSULTING ENGINEERING GEOLOGIST
1528 SOLANA DRIVE
BELMONT, CALIFORNIA

TELEPHONE LYTELL 1-1088

July 20, 1959

Utah Construction Company
One Hundred Bush Street
San Francisco 4, California

Attention: Mr. C. S. Davis, General Vice President

Subject: Stanford Two-Mile Linear Accelerator

Dear Mr. Davis:

After carefully reviewing the diamond drill core data of the Utah Construction Company together with the accompanying geologic data for the proposed site area for the Stanford Accelerator immediately South of Stanford University, walking out the entire area on two different occasions, as well as subsequently making an aerial site inspection and stereoscopic examination of the aerial photographs, the writer makes the following statement:

It is understood that a suitable subsurface investigation study will be made. Providing the above is satisfactorily completed, it is the considered opinion of the writer that final tunnel alignments can be located within the general proposed area which are entirely feasible for construction and which appear in all reasonable probability to be within design and operational tolerances as regards possible earth movements.

Respectfully submitted,

Clark E. McHuron

Clark E. McHuron

In duplicate
CEM:jj

APPENDIX E-2

BECHTEL CORPORATION ENGINEERS-CONSTRUCTORS
TWO TWENTY BUSH STREET · · · SAN FRANCISCO 4, CALIFORNIA

July 17, 1959

Dr. Edward Ginzton
Microwave Laboratory
Stanford University
Palo Alto, California

Dear Dr. Ginzton:

Enclosed is the report of our Chief Consulting Geologist - Roger Rhoades - concerning the site geology for the proposed Stanford Linear Accelerator.

Mr. Rhoades is a consultant for major hydro-electric and hydraulic studies and engineering with Bechtel Corporation as well as other clients in the United States, Australia, Pakistan, Canada and the South American countries. Before entering private practice, Mr. Rhoades was a geologist for the Tennessee Valley Authority and Chief Geologist for the Bureau of Reclamation.

In transmitting Mr. Rhoades' report, I should like to point out that the Hetch Hetchy Aquaduct, supplying water to San Francisco and other communities in the Bay Area, was recently constructed very close to and generally parallel to the site of the proposed accelerator.

If there are any other questions or problems with which we may be of service, please call on us.

Sincerely,

Wade Dickinson

WD/vs
Enclosure

APPENDIX E-2

ROGER RHOADES
CONSULTING GEOLOGIST

July 17, 1959

101 CALIFORNIA STREET
SAN FRANCISCO 11, CALIFORNIA

TELEPHONE DOUGLAS 2-4030
CABLE: RHODES

Mr. B. W. O. Dickinson
Bechtel Corporation
220 Bush Street
San Francisco, California

Dear Mr. Dickinson:

I have again reviewed the available geologic data, maps, cross sections, and report relevant to the seismic potential of the area in which it is proposed to erect the Stanford accelerator.

A tunnel or equivalent cut-and-cover system some two miles in length is proposed. This line is crossed by two faults and possibly by a third. There may also be other zones of shear or fault-like displacements of smaller magnitude which cannot be discerned on the ground surface. These are all old faults without any evidence of movement in the historic times. I consider them to be inactive faults, and that the chances of their resuming activity are negligible. For this reason, I can foresee no danger that the structure would be physically broken or offset, or its alignment distorted.

The San Andreas fault zone lies a few miles to the west. Stanford University has experienced earthquake vibrations emanating from this fault zone, notably in 1906. The accelerator installation in question would probably experience similar effects from time to time but probably not frequently.

I wish to make it clear that I am talking of two different things. First, the faults which actually cross the line of the proposed tunnel or cut-and-cover structure are old and inactive, and would not, in my opinion, jeopardize the structure. Second, a known active fault lies a few miles to the west of this area, and from it there will emanate earthquake effects in the future as in the past.

Naturally, the design and construction of the structure would incorporate the usual features for earthquake resistance; but this is standard engineering practice in regions where earthquakes are expectable.

Sincerely yours,

Roger Rhoades

Roger Rhoades
Consulting Geologist

RR:dk

APPENDIX E-3

KAISER ENGINEERS
DIVISION OF HENRY J. KAISER COMPANY
KAISER BUILDING • OAKLAND 12, CALIFORNIA

July 16, 1959

Dr. F. V. L. Pindar
Associate Director
Hansen Laboratories of Physics
Stanford University
Palo Alto, California

Dear Dr. Pindar:

In reply to your inquiry with respect to the feasibility of tunneling in the proposed location for the Stanford Linear Accelerator, the following is the comment of our geologist, Mr. D. J. Frost.

Based upon a field reconnaissance of the proposed site and adjacent area, it is his opinion that:

1. The proposed tunnels will pass through and be constructed in rocks which will afford better general tunnel driving conditions than are average for the general Central Coast Range area of California.

2. The two minor fault fracture areas which cross the tunnel site are thrust type, are of probable Pleistocene age, and are now inactive. Since they are unrelated to the San Andreas System complex, no significant movement is expected along these fracture zones.

3. Barring general catastrophic wide spread West Coast earth movements, the long range physical stability of the constructed tunnels would be expected.

These opinions are based on an inspection of the surface, and on general knowledge and experience in this area. We recommend, of course, that a program of investigation of the proposed site by core drilling be undertaken.

Very truly yours,

KAISER ENGINEERS
Division of Henry J. Kaiser Company

David F. Shaw

David F. Shaw
Vice President

DFS:hs

KAISER ENGINEERS
ENGINEERING—CONSTRUCTION • CONTRACTING SINCE 1914

APPENDIX F

SELECTED REFERENCES

The following references were extensively consulted during the preparation of this report. Many other sources have been examined, and a complete bibliography is being compiled. However, publications listed are those which are most pertinent to the present investigation.

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Appendix 7

WILLIAM M. BROBECK & ASSOCIATES
Engineering Research-Design-Development

July 21, 1959

1920 Park Blvd.
Oakland 6, California
Glencourt 2-0876

Joint Committee on Atomic Energy
Room F-88, Capitol Building
U. S. Senate Post Office
Washington 25, D. C.

Dear Sir:

I am enclosing an excerpt from our report "Review of the Stanford Proposal for a Two-Mile Linear Accelerator", Appendix VII, pages 2, 3 and 4, which provides the itemized costs of operation of the accelerator as planned at the time of our report.

In reply to the request for the annual power cost for the accelerator as now planned, I am enclosing a separate statement.

In reply to the request for the change in construction cost due to a change from 480 to 240 Klystrons, we estimate a reduction of $3,700,000 before contingency and escalation.

I am also enclosing the copy of my remarks at the hearing approved with minor corrections.

Very truly yours,

William M. Brobeck

encl.

WILLIAM M. BROBECK & ASSOCIATES

PAGE 1
DATE 7/22/59

SUMMARY OF POWER COST ESTIMATE
FOR OPERATION OF STANFORD TWO-MILE ACCELERATOR
AS PLANNED JULY 1959

Basis

This summary is prepared from the Brobeck Review of the Stanford accelerator, June 1958, with the following considerations:

1. The number of Klystrons is reduced from 480 to 240.
2. Klystron DC power input is based on an average of 240 pulses per second and a peak RF pulse power of 6 mw per Klystron. This average to apply to 24 hour per day 365 day per year operation. This is the average operating level specified by Stanford as now being planned.
3. A reduction in Klystron heating power has been made as a result of tube development during the last year.
4. Klystron focusing power has been eliminated through the use of permanent magnet focusing.
5. The power requirement of the Klystron factory has been eliminated, as it is now assumed that Klystrons will be purchased. Power requirements of other buildings are based on the buildings described in the 1958 Review.
6. Power requirements for pumps, fans, air conditioning, controls, refrigeration handling equipment, magnets and other miscellaneous equipment are taken from the 1958 Review. This design is not necessarily suited to the present number of Klystrons and present operating conditions.
7. Power rates are obtained from Pacific Gas and Electric Company Schedule A-13, which is the current applicable schedule.
8. All loads are assumed 90% power factor.
9. No provision is made for the power requirements of additional experimental equipment not part of the initial construction project.
10. To limit the power demand the accelerator will not be operated at over 8000 kva power input to the Klystron rectifiers except at nights and on Sundays and holidays.

WILLIAM M. BROBECK . ASSOCIATES

PAGE 2
DATE 7/22/59

AVERAGE POWER ESTIMATE
BASED ON TABLE OF APPENDIX II, P. 13, 1958 REVIEW

	Connected Load KVA	Billing Demand KVA	Use Factor	Average Load KVA
Klystron Rectifiers	23,200	8,000	--	3,900
Other tunnel loads	5,500	4,450	--	3,200
Tunnel total	28,700	12,450	--	7,100
Beam Switchyard	3,650	2,000	.9	1,800
End Station	3,900	3,300	.5	1,650
Prototype	2,250	2,250	.5	1,125
Admin., Shops, etc.	2,270	2,270	.5	1,135
Air Conditioning	1,000	1,000	.5	500
Pumps & Fans	3,690	2,750	.8	2,200
Compressors & Refrig.	4,120	4,120	.8	3,320
	49,580 kva	30,140 kva		18,830 kva
Kilowatts at .9 PF	44,600 kw	27,100 kw		16,950 kw

Annual cost as per PG&E Schedule A-13 - $1,370,000

WILLIAM M. BROBECK & ASSOCIATES

PAGE 1 of 3
DATE 7/22/59

Excerpts from Appendix VII, "Recurring Costs",
in "Review of the Stanford Proposal for a Two-Mile Linear Accelerator",
by William M. Brobeck & Associates, dated June 1958

Section A - Operating Costs

Klystron Factory

Engineers & Draftsmen	$ 45 *
Technicians	862
Machinists & Brazers	281
Electro-Platers & Specialists	112
Subtotal	$ 1,300
Material	1,000
Total	$ 2,300

Accelerator Operations & Maintenance

Accelerator Operators	$ 300
Machinists & Brazers	183
Accelerator Technicians	275
Electronic Technicians	305
Maintenance & Crafts	153
Engineers & Draftsmen	132
Subtotal	$ 1,348
Power	1,500
Other Material	730
Total	$ 3,578

* Shown in thousands

WILLIAM M. BROBECK & ASSOCIATES

Excerpts from Appendix VII, "Recurring Costs" (cont'd)

PAGE 2 of 3
DATE 7/22/59

Research

Senior Scientist	$ 130	*
Junior Scientist	140	
Staff Scientist	200	
Graduate Student	160	
Engineers	200	
Accelerator Operators	24	
Draftsmen	95	
Electronics Technician	325	
Laboratory Technician	193	
Mechanical Designer	36	
Nurse	15	
Photographer	10	
Radiological Technician	24	
Machinist & Brazer	366	
Laborers	92	
Other Crafts	165	
Subtotal	$ 2,175	
Power	210	
Material	900	
Total	$ 3,285	

Administrative & General Service

Adm. Assistants & Section Heads	$ 266	
Secretaries, Clerks, Helpers	640	
Maintenance	275	
Subtotal, Labor	$ 1,181	
Janitor & Plant Security (Service contracts)	165	
OASI Tax & Comp. Insurance	146	
Group Life Insurance & Retirement	175	
Plant Maintenance Contracts	250	
Communications	60	
Travel	30	
Misc. Utilities, Mat'l & Other Costs	400	
Total	$ 2,407	
University Allotment	$ 250	
Equipment not related to Construction	$ 1,200	
Total Operating Costs	$13,920	

* Shown in thousands

WILLIAM M. BROBECK & ASSOCIATES

Excerpts from Appendix VII,
"Recurring Costs" (cont'd)

PAGE 3 of 3
DATE 7/22/57

Section B - Recurring Plant & Equipment Costs

General Plant

Machine Improvements 2,000 x 1/4	$ 500	*
Plant Improvements - General	500	
Subtotal	$ 1,000	

Line Items

Large Magnetic Spectrometer	$ 600	
Bubble Chamber or Equivalent 2,000 x 1/2	1,000	
Additional Observation House 1,500 x 1/4	375	
Shielding Changes 3,000 x 1/4	750	
	$ 2,725	
Total Recurring Costs	$16,745	

* Shown in thousands

Appendix 8

RAYTHEON MANUFACTURING COMPANY
Research Division
Waltham 54, Massachusetts

July 15, 1959

Messrs. Melvin Price and
Chet Holifield
Joint Committee on Atomic Energy
U. S. Capitol, Washington, D. C.

Gentlemen:

For your consideration of the Linear Accelerator proposed to be constructed at Stanford University, I would like to add to the record the fact that my analysis of this proposal was favorable when I, as Director of the Research Division of the U.S.A.E.C., first received it in 1956. Now, as a private citizen I still believe it would be in the country's best interests for this project to be funded by the Federal Government.

Some of the points brought out in my analysis of the project are the following:

1. The proposed accelerator has been proven technically feasible and the cost estimates can be relied on as being reasonably firm.

2. The accelerator would open up to experiment an important new area in the science of high energy physics and investigations which could be carried out with it would supplement those with other accelerators of the world, giving additional meaning to the results achieved in the whole program.

3. Its construction at Stanford University, with the proposed agreements for use by other qualified scientists, would guarantee its design and use by those with the best qualifications.

4. No other source of funds in the required amount can be expected to become available.

5. The project can be expected to add measurably to American prestige in science and as a by-product to increase our capability in the militarily important technology of microwave generation.

I consider it unfortunate that the project has been delayed so long for consideration by various scientific advisory groups and for the resolution of other matters affecting the support of scientific activities by the Government. It is indeed gratifying that the project is now before your subcommittee for final action, and I hope that it will be possible to go ahead with it without further loss of irretrievable time.

Sincerely yours,

T. H. Johnson
Vice President

THJ:prb

Appendix 9

W. W. Hansen Laboratories of Physics
STANFORD UNIVERSITY
Stanford, California

Microwave Laboratory
High Energy Physics Laboratory
DAvenport 3-2441

July 22, 1959

The Honorable Melvin Price, Chairman
Subcommittee on Research and Development
Joint Committee on Atomic Energy
Congress of the United States
Washington, D. C.

Dear Sir:

During the hearings before your Committee on the proposed two-mile linear electron accelerator on July 14 and 15, we were requested to provide for the record an up-to-date estimate of the annual power costs for the accelerator and its associated research facilities.

We estimate that the annual power consumption will be 139,000,000 kilowatt-hours. Based upon a rate of 9.294 mills per kilowatt hour, the total annual power cost will be $1,300,000. This amount is included in the estimated $15,000,000 total annual operating budget.

A detailed breakdown of our power estimates is appended. Please let us know if further details are desired or if there are additional questions which we may be able to clarify.

Respectfully,

E. L. Ginzton, Director
Microwave Laboratory
W. W. Hansen Laboratories of Physics
Stanford University

cc: Mr. James T. Ramey
Executive Director
Joint Committee on Atomic Energy
Congress of the United States
Washington, D. C.

Jul. 20, 1959

ANNUAL POWER COST ESTIMATES

Proposed Two Mile Linear Electron Accelerator

Load	Connected Load (KVA)	Billing Demand (KVA)	Load Factor	Average Load (KVA)
Klystron power supplies	23,200	8000(2)	.488	3900(1)
Klystron auxilaries	600	300	.90	270
Klystron focusing(3)	0	0		0
Deflection system	800	40	1.00	40
Booster pumps	200	200	1.00	200
Controls	400	350	.9	315
Vacuum gauges	400	400	1.0	400
High vacuum pumps	400	400	1.0	400
Klystron tunnel lights	1000	500	1.0	500
3Ø Auxiliary power	400	200	0.2	40
Klystron heaters(4)	120	75	1.0	75
Water pumps	400	300	.9	270
Accel. water heater	600	300	.9	270
Roughing pumps	600	6	1.0	6
Monorail	200	10	1.0	10
Accel. Tunnel	480	120	.01	1
	29800 KVA	11201 KVA	Total tunnel requirements	6697 KVA

Jul. 20, 1959

Load	Connected Load (KVA)	Billing Demand (KVA)	Load Factor	Average Load (KVA)
Beam switchyard	3650	1800	1.00	1800
End station	3900	3300	.60	1980
Prototype	2250	2250	.60	1350
Adm. - shops, etc.	2270(5)	2270	.50	1135
Air Conditioning	1000	1000	.60	600
Pumps and fans	3690	2750	.60	1650
Compressors and Refrig.	4120	4120	.60	2472
	20880	17490		10987
Total	50,680 KVA	28,691 (KVA)	.616	17,684 KVA
	(45,612 Kw)(6)	(25,822 Kw)		(15,916 Kw)

Calculated rate: (From schedule A-13, Pacific Gas & Electric Co., San Francisco, Calif.) 9.294 mills/kw hr.

Total Annual cost: 15,916 x 8760 x .009294 = $1,295,808

(1) Based upon operation on the average at 11 Bev (half maximum energy) and 240 pulses per second average repetition rate.

(2) Klystron power supplies will be limited to this level except during off-peak hours (i.e., higher demand will be permitted from 10:30 p.m. to 6:30 a.m. and holidays).

(3) It is assumed that permanent magnet focusing is used.

(4) Klystron heaters require 400 watts maximum, 250 watts expected.

(5) Reduced 900 KVA to allow for elimination of klystron factory.

(6) A power factor of 0.9 has been used throughout.

APPENDIX 10

CORRESPONDENCE ON ORGANIZATIONAL AND ADMINISTRATIVE POLICIES

AUGUST 10, 1959.

Mr. JOHN A. McCONE,
Chairman, U.S. Atomic Energy Commission,
Washington, D.C.

DEAR MR. McCONE: In reviewing the transcript of the open hearing on the Stanford linear accelerator, the Commission's testimony was somewhat vague as to whether or not the AEC would approve in advance the basic organizational and administrative policies for the use of the accelerator.

In view of the Government's proposed investment of more than $100 million in the facility and of $15 million annually in operations, it would appear necessary and desirable that AEC must have the right to approve the basic organizational and administrative policies for the use of the accelerator as a national project.

I would like to have some assurance on this matter at the time the Joint Committee meets on the authorization of this project.

Sincerely yours,

CLINTON P. ANDERSON, *Chairman.*

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., August 17, 1959.

Hon. CLINTON P. ANDERSON,
Chairman, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR SENATOR ANDERSON: This is in reply to your letter of August 10, 1959, concerning Commission approval of the basic policies for the use of the Stanford linear accelerator.

I can give you every assurance that the Commission will have the right to approve in advance the basic organizational and administrative policies governing the use of this national facility. This right of approval will be incorporated in the basic contract agreement between the U.S. Atomic Energy Commission and Stanford University.

Sincerely yours,

JOHN A. McCONE, *Chairman.*

APPENDIX 11

CORRESPONDENCE ON POWER REQUIREMENTS

JULY 23, 1959.

Hon. FRED A. SEATON,
Secretary of the Interior, Department of the Interior,
Washington, D.C.

DEAR MR. SECRETARY: You are doubtless aware of a pending proposal of the Atomic Energy Commission for authorization of a linear electron accelerator at Stanford University at Palo Alto, Calif. The initial power requirements for this installation would be 60,000 kilowatts and ultimately might go as high as 240,000 kilowatts.

It occurs to me that the power requirements of a publicly owned installation of this character and the cost of the service have a direct bearing on considerations in connection with the proposed power intertie between the Bonneville (Pacific Northwest) and California systems.

Therefore, I am bringing this subject to your attention for relaying to the Bonneville Power Administrator in connection with the review of the proposed intertie on which a report is to be made to the Committee on Interior and Insular Affairs by December 30, 1959.

I am also bringing the matter to the attention of the Governors of California, Oregon, and Washington, Mr. Owen Hurd, of Kennewick, Wash., chairman of the Pacific Coast Power Coordinating Committee, and Mr. James K. Carr, of the Sacramento Municipal Utility District, Sacramento, Calif.

Sincerely,

CLINTON P. ANDERSON,
Chairman, Subcommittee on Irrigation and Reclamation.

U.S. DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington, D.C., July 29, 1959.

Hon. CLINTON P. ANDERSON,
U.S. Senate, Washington, D.C.

DEAR SENATOR ANDERSON: This is in reply to your letter of July 23 regarding the power requirements for a proposed linear electron accelerator at Stanford University at Palo Alto, Calif.

In accordance with your request, a copy of your letter will be sent to Bonneville Power Administration in connection with a review of the proposed California intertie on which a report is to be made to the Committee on Interior and Insular Affairs by December 30, 1959.

Sincerely yours,

FRED S. AANDAHL,
Secretary of the Interior.

JULY 30, 1959.

Gen. A. R. LUEDECKE,
General Manager, U.S. Atomic Energy Commission,
Washington, D.C.

DEAR GENERAL LUEDECKE: Mr. McCone's July 27, 1959, letter to Senator Anderson on the subject of electrical energy cost estimates for the proposed Stanford accelerator refers to the most recent Stanford computations of such costs.

The most recent Stanford estimate that we have is dated July 20, 1959. It is based on operation at an average electron energy of 11 Bev., an estimated annual energy consumption of 139 million kilowatt-hours and an energy rate schedule of 9.294 mills per kilowatt-hour, resulting in a total annual energy cost estimate of $1,300,000.

We would appreciate receiving the comparable annual energy cost estimate for the accelerator modified to accelerate electrons to a maximum of 45 Bev.

Sincerely yours,

JAMES T. RAMEY, *Executive Director.*

U. S. ATOMIC ENERGY COMMISSION,
Washington, D.C., August 10, 1959.

Mr. JAMES T. RAMEY,
Executive Director, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. RAMEY: This is in reply to your letter of July 30, 1959, concerning the estimated annual power costs for the Stanford accelerator should it be modified to accelerate electrons to a maximum energy of 45 Bev.

Stanford personnel have estimated that a machine capable of operating at a maximum energy of 45 Bev. would operate at an average energy of 22 Bev. with an annual power consumption of 280 million kilowatt-hours. Using the Pacific Gas & Electric Co. standard rate schedule of 9.294 mills per kilowatt-hour, the annual power cost would be approximately $2,600,000. There are indication that the cost per kilowatt-hour can be reduced by negotiations at a later date, when more definitive information regarding the project power demand is available.

It should be noted that the Commission intends to submit to the Joint Committee on Atomic Energy for separate authorization any project that increases the number of klystrons beyond the present 240 in order to increase the energy of this macihne.

If we can be of any further assistance, please let us know.

Sincerely yours,

———— ————, *General Manager.*

APPENDIX 12

SUTRO TUNNEL INVESTIGATION

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., July 31, 1959.

MR. JAMES T. RAMEY,
Executive Director, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. RAMEY: In connection with the recent Stanford accelerator hearings the Commission was asked to explore the possibility of using the Sutro tunnel near Virginia City, Nev., as a substitute for the tunnel proposed for construction at Stanford University.

An onsite investigation of the Sutro tunnel made by Commission engineers indicates the tunnel width varies from 8 to 13 feet, and the height varies from 9 to 10 feet. To serve the accelerator project the tunnel would have to be enlarged and lined in order to house the klystrons, and a second tunnel would have to be constructed to house the accelerator tube.

The surrounding terrain is such that the floor of the target building would be approximately 89 feet above the present grade, necessitating a vast amount of fill for the building complex and experimental area. Additional cost factors over the Stanford estimate include isolation pay for labor, provision for family housing within a reasonable commuting distance, development of an adequate water supply and provision for sufficient electric power. With respect to this last item, the Sierra Pacific Power Co. would require an AEC guarantee against company loss on a new 50,000 kilowatt powerplant, transmission lines and transformer, altogether costing more than $10 million.

In addition to the above, the 10-foot tunnel for the accelerator tube must be absolutely level. Since the Sutro tunnel, which would house the klystrons, has an appreciable grade,[1] the power losses occasioned by the additional length of the connecting wave guide would be substantial.

Under the circumstances the Sutro tunnel should not be considered as a suitable site for the location of the Stanford linear accelerator.

Sincerely yours,

JOHN H. WILLIAMS,
Director, Division of Research.

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., August 6, 1959.

MR. JAMES T. RAMEY,
Executive Director, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. RAMEY: This is in reference to my letter to you dated July 31, 1959, concerning use of the Sutro tunnel near Virginia City, Nev., as a substitute for the one proposed in connection with the Stanford accelerator project.

In that letter we stated that the Sutro tunnel had an appreciable grade. The actual grade is 0.245 percent, which at first glance appears slight. However, over the 10,000-foot total distance of the tunnel this would amount to 24.5 feet. The total grade change for use of this project is therefore appreciable, but we suggest that the letter be modified to indicate the actual grade.

Thank you for your cooperation in this matter.

Sincerely yours,

JOHN H. WILLIAMS,
Director, Division of Research.

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[1] Following letter contains grade data.

APPENDIX 13

CORRESPONDENCE ON STANFORD UNIVERSITY SITE FEASIBILITY STUDY

CONGRESS OF THE UNITED STATES,
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D.C., July 28, 1959.

Gen. A. R. LUEDECKE,
General Manager, U.S. Atomic Energy Commission,
Washington, D.C.

DEAR GENERAL LUEDECKE: In accordance with Mr. Price's request during the recent Stanford accelerator hearings we have received a report from Dr. Ginzton of Stanford on the feasibility of the site proposed for the accelerator.

We understand the Commission has also received a copy of this report which is entitled "Site Feasibility of Stanford's Proposed 2-Mile Linear Electron Accelerator," by Frank W. Atchley and Robert O. Dobbs, Stanford University, dated July 1959.

We would appreciate receiving the Commission's comments on this report. In particular we would appreciate receiving information on allowances included in the Commission's cost estimate for tunnel construction in the event adverse conditions are found in the region proposed for the construction of the tunnels.

We are planning to include the site report submitted by Dr. Ginzton in the record of the Stanford accelerator hearings. We would also like to include any comments the Commission has on the report in the record. Therefore, we would appreciate a prompt reply.

Sincerely yours,

JAMES T. RAMEY, *Executive Director.*

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., August 10, 1959.

Mr. JAMES I. RAMEY,
Executive Director, Joint Committee on Atomic Energy, Congress of the United States.

DEAR MR. RAMEY: This is in reply to your letter of July 28, 1959, requesting the Commission's comments on the Atchley and Dobbs report on "Site Feasibility of Stanford's Proposed 2-Mile Linear Electron Accelerator."

We are in general agreement with the conclusions of the Atchley and Dobbs report and their considered opinion that the proposed site for the Stanford accelerator is a feasible location.

The Commission currrently has a research contract with Stanford University, which has been modified to provide approximately $90,000 for core drillings and test borings to be made of the proposed site as soon as possible. The resultant information will firm up the exact alinement of the two tunnels and provide additional information that will assist in refining the present tunnel cost estimates. In this connection, the following comparitive tunnel cost estimates of Stamford, Brobeck, and the Atomic Energy Commission indicate that Commission engineers reflected a small increase over the Brobeck estimates and a substantial increase over th eStanford estimates:

Tunnel cost detail

[In thousands]

Item	Stanford	Brobeck	AEC
Klystron tunnel	$6,705	$8,853	$9,296
Accelerator tunnel	1,930	3,190	3,690
Cross drifts and tubes	1,160	926	926
Vents and escape hatches	110	467	467
Switchyard tunnel work	297	522	522
Vaults and alcoves		1,522	1,522
Tunnel lighting	218	341	341
Total	10,420	15,831	16,764

The Brobeck and Commission estimates were based on existing geological information outlined on page II–7 of the Brobeck analysis. No amount is included in the tunnel estimates for unusually adverse conditions since actual tunnel construction in the immediate area (Hetch Hetchy Aqueduct) indicates no unusual conditions are to be expected. The project contingency of 15 percent ($13,400,000) is included to take care of any unusual conditions encountered in the tunnel construction or elsewhere in the project should it be required.

Sincerely yours,

———— ————, *General Manager.*

APPENDIX 14

CORRESPONDENCE ON PATENTS AND ROYALTIES

AUGUST 5, 1959.

Gen. A. R. LUEDECKE,
General Manager, U.S. Atomic Energy Commission,
Washington, D.C.

DEAR GENERAL LUEDECKE: We would like to receive information on the subject of patents relative to the proposed Stanford linear electron accelerator project. Specifically we would like to know what significant items proposed to be used in the accelerator are patented, who holds the patents, and what the Government's liability may be relative to fees or royalty payments for the use of such patents or patented devices. For example, we would like to know the patent situation with respect to the klystron tubes.

We would also appreciate information on what kind of patent article will be used in the contract for the development and operation of the linear acelerator, including the handling of background patents, if any.

Sincerely yours,

JAMES T. RAMEY, *Executive Director.*

U.S. ATOMIC ENERGY COMMISSION,
Washington, D.C., August 19, 1959.

Mr. JAMES T. RAMEY,
Executive Director, Joint Committee on Atomic Energy,
Congress of the United States.

DEAR MR. RAMEY: Your letter of August 5, 1959, inquiring as to certain patent aspects of the Stanford linear accelerator proposal, is acknowledged.

It is believed that you will appreciate that the technical aspects of the accelerator are only in the formative stage and that it may be several years before detailed decisions will be made as to its design or the components to be incorporated therein.

During the past several years there have been a number of items conceived during the course of developments under the Stanford atomic energy basic research contract At–04–3–21 which, if proven in future research, might constitute important components to be incorporated in the accelerator. The Commission, by virtue of the patent provisions of said contract, would acquire the rights in any such developments that have been made in the course of said contract. There may be some items developed under a Navy research contract with Stanford as to which the Government would acquire a governmental license. There may also be other items privately developed and owned which may be incorporated in the linear accelerator. However, it is not believed possible to identify any specific items at present, since, as noted no final determination as to the particular components to be employed has been made.

At present, one significant item proposed for use, that is covered by privately owned patents, is the klystron tube. It is to be appreciated that there may be other components that will be selected for inclusion that would be the subject of privately owned patents.

It is understood that the basic developments in the klystron were made by Stanford investigators prior to any Government-sponsored work and that a considerable number of patents have been secured by Stanford and Sperry Gyroscope Co. (now a division of Sperry-Rand Corp.) on such component. Certain work at Stanford, starting sometime in 1938, was sponsored by Sperry. Sperry

and Stanford in March 1946 negotiated an agreement, nullifying an earlier 1938 agreement, under which Sperry acquired the exclusive administration of the licensing of the klystron patents. Sperry has granted licenses to make and sell klystrons at 3 percent royalties. Stanford's share of royalties was 1½ percent on all klystrons until January 1, 1956. After extensive negotiations, the Defense Department entered into an agreement on January 1, 1956, with Sperry, Stanford, and Raytheon, under which, in addition to settling for $276,441 for past Government infringement, Sperry and Stanford agreed that future royalties on klystrons for Government end use would be at the rate of 2½ percent. Therefore, should klystrons be employed, and in the absence of any other arrangement, the Atomic Energy Commission may very well be obligated to pay Sperry licensees the 2½ percent royalty on klystrons.

President Sterling of Stanford has advised Chairman McCone that Stanford would, if necessary, consider waiving its share of the klystron tube royalties for those tubes purchased by Stanford under the proposed contract. It is understood that 50 percent of all royalties is retained by Sperry and that of the 50 percent royalties coming to Stanford its share is 45 percent, the balance being distributed in designated portions to the Hansen estate and the Varian brothers, as individuals.

No specific contract negotiations have been undertaken with Stanford as to the patent provisions to be incorporated in the contract. The Commission will expect to employ the same type of provision in the development and operation contract as has been employed in other research, development, and operating contracts, namely a type A patent article. The type A patent article has been incorporated in other research and development contracts with Stanford. It is anticipated that the Commission will hold Stanford harmless as respects research, development, and operation, the same as other contract operators of Commission installations, subject to such contract operators securing patent indemnity in favor of the Government as respects standard parts and components purchased and employed in the contract work. If research and development is to be conducted on specific components that are the subject of Stanford patents or patent applications, the Commission will employ background license provisions covering such items or components to the extent that Stanford can grant the same without payment of royalties. It is recognized that if it is necessary to conduct research and development on the klystron tube, that it may not be possible to secure more than a waiver from Stanford of its share of royalties under existing Stanford agreements.

I ttrust that the foregoing information is a satisfactory response to your inquiry.

Sincerely yours,

A. R. LUEDECKE, *General Manager.*

AUGUST 19, 1959.

Gen. A. R. LUEDECKE,
General Manager, U.S. Atomic Energy Commission,
Washington, D.C.

DEAR GENERAL LUEDECKE: The receipt of your August 19, 1959, letter on the subject of patents relative to the proposed Stanford linear accelerator is acknowledged.

We would appreciate receiving estimates of annual royalty costs for klystron tubes for the proposed machine based on the royalty percentages given in your letter. Please supply estimates on the assumption that Stanford waives its share of the royalties and on the basis that Stanford does not waive its share. Also please indicate the estimated cost per tube and estimated tube life upon which the royalty estimates are based.

Sincerely yours,

JAMES T. RAMEY, *Executive Director.*

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